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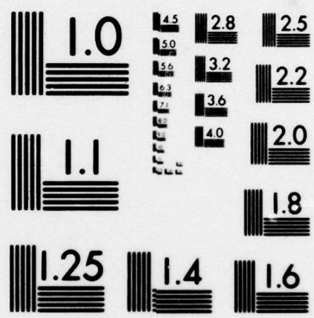

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FOREIGN TECHNOLOGY DIVISION

LASER CONQUERS THE SKY

by

V. Ye. Zuyev

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U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere.
When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

Page 1.

Correspcnding member of Academy of sciences of the USSR.

V. Ye. Zuyev.

Western-Siberian book publishing house publishes for the wide circle cf the readers of the series of the books, which tell about most urgent problems and prcspects for scientific-technical revclution under conditions of Siberia. Their authors are scientific SO AN USSR [СОАН СССР - Siberian Department of the Academy of Sciences of the USSR] and leading specialists of the industrial enterprises of Western Siberia.

Series "Science - to production" includes the books, dedicated to experiment in the introduction in the national economy of the automated control systems, to cellaboration cf Siberian scientists with the tcilers of agriculture on equipment of state farms and kolkhozes by all gadgets, communication/connections cf fundamental sciences and industry, principal directions of scientific-technical

revolution, most significant discoveries and achievements of the scientific collectives of SC AN USSR.

The books from series "Continent of the future" show the place of Siberia in all-Union division of labor and the role of its natural resources in further development of socialist productive forces, system of the store/adding up and already existing national-economic complexes, path and scientific methods of the solution of the large/coarse economic problems of Siberia, connected with the accelerated development of productive forces of the East areas of the country.

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LASER CONQUERS THE SKY

Page 3. No Typing.

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The creation of lasers with their surprising properties opens exclusively tempting prospects for their manifold application/uses virtually in all areas of science and technology.

Special place is occupied by lasers in the communicating systems, transmission of information, location, ultra-precise determination of distance of the distant object/subjects, remote investigation of different atmospheric phenomena which determine processes of weather and climate formation.

The progress in the use of lasers in all systems, workers under conditions of the atmosphere, first of all depends on our knowledge about interaction of laser emission/radiation with complex and variable medium - the atmosphere. The proposed to the reader book is dedicated to different aspects of this problem; in it are examined questions of the absorption of laser energy by atmospheric gases, scattering it by aerosols, the effect of turbulence of the atmosphere on the parameters of laser beams, the so-called nonlinear effects, which accompany the propagation of powerful/thick laser emission/radiation. Special attention is given to the problem of the laser sounding of the atmosphere. Author of the book is a corresponding member of the Academy of Sciences of the USSR and doctor of physicomathematical sciences.

The book is intended for the wide circle of the readers, workers in the region of optics and spectroscopy of the atmosphere, meteorology, geophysics, astrophysics, specialists, connected with the development of different optical-electronic instruments.

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INTRODUCTION.

To quantum electronics and its creation - laser technology - belongs the outstanding role in further development of society. It is connected with the whole series of the surprising properties of laser emission/radiation, which create the tempting prospects for its use virtually in all spheres of human activity.

The creation of lasers significantly contributes to the development of the qualitatively new stage of the practical mastery/adoption of the scale range of the electromagnetic waves - one of the most important problems of scientific-technical progress.

The optical range of the electromagnetic waves is utilized by man from immemorial times. It suffices to say that our environment we see with the aid of optical waves, and human eye - an unsurpassed indicator and the receiver of optical radiation. The first stage of its rapid development of optician it survived long before discovery of radio waves and invention of radio. "Optical revolution" is connected with the creation of instruments which significantly

expanded the possibilities of human eye during the investigation of macrocosm (telescopes) and of microcosm (microscopes).

The following noticeable landmark in the development of optics became discovery of the spectra of substances. Spectroscopy and spectral analysis played and they continue to play the outstanding role in the investigation of the structure of matter.

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In the second half XIX century, Maxwell theoretically demonstrated the existence of radio waves, and Hertz reveal/detected them in experiment, after expressing them, however, the doubt apropos of the practical value of its discovery. But in 1895 outstanding Russian physicist A. S. Popov transmitted the first roentgenogram and thereby placed the foundation of the mastery/adoption of the radio-frequency range of the electromagnetic waves. Optics by that time was the sufficiently developed science.

Radio waves soon became basic communications of society. Scientists and engineers shortly tamed radio waves, after making them by a peculiar coachman, with the speed of light carrying information up to enormous distances. Modern life is not possible to visualize without radio communication, radar, television.

Occurred, it seemed, the paradoxical phenomenon: the radio waves, discovered much later than optical waves, they considerably rather found practical application/use. While the electromagnetic waves of radio-frequency range extremely violently invaded the sphere of communication/connection, the mastery/adoption of optical range for the transmission of information progressed forward extremely slowly. Scientists and engineers for a long time did not have sources and radiation detectors which could compete with sources and receivers of radio waves.

The creation of lasers opened the completely unexpected possibilities of using the optical wave band of electromagnetic emission/radiation. First of all discussion deals with the use of optical waves for the transmission of information, location, ultra-precise determination of distance of the distant object/subjects. Then became obvious the prospect of their application/use for the remote sensing of the atmosphere for purpose of data finding on the pressure, the density, the temperature, the humidity, the wind, the clouds, the aerosols and other atmospheric parameters.

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The emission frequency of laser in million or more times is higher than the frequency of radio wave range. This means that and the quantity of different information, which can transmit laser beam, in truth infinite in comparison with the informative ability of radio waves. But in connection with the extreme narrowness of the emitted by laser section of wavelengths (about the millionth portion of the value of wavelength), the laser communication line can virtually work without interferences, since overwhelming majority by their it is not difficult to cut off narrow-band interference filters.

Small divergence of laser emission provides the possibility of the transmission of information to extremely large distances. So, already on the contemporary level of development of laser technology it is possible to accomplish interplanetary two-way communication within the limits of the Solar system.

The use of lasers in locating and ranging systems promises an essential increase in the accuracy of location and measurements. Laser locators are capable to reveal/detect object/subjects by size/dimensions into the tenths of meter, which are located beyond several kilometers, of determining the geometric form of large/coarser objects. The accuracy of measurements virtually depends

nct on distance, but on duration and slope/transconductance of laser pulse. Contemporary laser range finders measure the distance with an ackuracy to decimeters.

If we utilize for laser range finding not a time interval between the maximums of that emitted and reflected from the target/purpose of momentum/impulse/pulses, but one of the newest methods of the study of the distortions of wave front, then it is possible to measure the distances with the accuracy of the order of the wavelength of emission/radiation, i.e., to the portions of microns. Under management/manual author one of such methods they develop/process in the institute of optics of the atmosphere of SO AN USSR.

The contemporary methods of spectral analysis make it possible to detect the traces of different substances under quite diverse conditions. Are already investigated the spectra of the hugest quantity of substances in solid, liquid and gaseous state. Nevertheless, the possibilities of spectroscopy far are not exhausted.

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As interference serves the limited resolution of spectrometers. Even

the best, most unique spectrometers in which are utilized the classical methods of production of a spectrum, thus far cannot give free from distortions picture during the investigation of substance in gaseous state. Meanwhile the solution of this problem - each spectroscopist's dream, since the completely solved and undistorted spectra of absorption of substances in gas phase contain the most complete information about intra- and intermolecular interactions, about the mechanism of interaction of world/light with substance.

In order to obtain the clear and undistorted spectra of the majority of substances in the gaseous state, it is necessary to attain spectral resolution, which is measured by the thousanths of kayser. The expressed in kaysers wavelengths of laser emission are equal to approximately 10^3-10^4. So the emission/radiation of the most widely used lasers on ruby and on carbon dioxide has a wavelength of approximately 14,500 and 940 kaysers [1].

FOOTNOTE [1]. In optics for measuring the wavelengths of emission/radiation, are utilized kayser (cm^{-1}), Angstrom (Å), nanometer (the billionth of meter), microns (μ), millimicron (nm). 1 cm^{-1} = 30,000 MHz. 1 μ = 10,000 Å. For translation/conversion of wavelength of emission/radiation, expressed in Angstrom, into kaysers one should remember that these values conversely are proportional and their value coincide for wavelength 1 μ, which is equal to 10,000 Å, or 10,000 cm^{-1}. ENDFOOTNOTE.

Thus, the required spectral resolution is characterized by the value, which comprises the millionth and even decamillion portions of the length of one waves. The best spectrometers have resolution by an order below and cannot give the spectra, free from distortions.

To obtain the spectra of substances, in that form, in which they exist in nature, important practical problem. In particular, only having completely solved undistorted spectra, we can quantitatively rate/estimate the losses of laser emission/radiation during its propagation in gaseous medium (in the atmosphere).

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Solution of the problem of obtaining the spectra of substances of superhigh resolution will give to us not only new knowledge about the structure of matter, but also it will become new development stage of optics and of practical mastery/adoption of the optical range of the electromagnetic waves.

The outstanding role in the new bloom of spectroscopy will play lasers. The connection of two properties of laser emission/radiation - high monochromaticity and ability to control a change in the

wavelength - serves as basis of new in principle promising method of spectroscopy of superhigh resolution. Now we already can speak about the first results of its realization. Under the author's guidance in the Institute of optics of the atmosphere of SO AN USSR and in the laboratory of infrared radiations of Siberian physiotechnical institute by Tomsk state university is created the first laser spectrometer with the aid of which is investigated the spectrum of absorption of the earth's atmosphere in area of laser emission on ruby.

Laser technology opens completely new possibilities in the solution of this general human problem as the problem of short term and long-range weather forecasts. Its successful solution has the enormous national economic value. It is calculated, for example, that an increase in the authenticity of the forecast/predictions in all by 10/0 capable of giving to our country to 1 billion rubles of annual economic effect.

It seems at first glance incomprehensible, what ratio/relation to weather forecasting have lasers. However, entire problem of precise weather forecasting can be divided into three independent and connected problems: 1) the accumulation of the initial data on the atmospheric parameters; 2) the creation of mathematical theories and algorithms of the forecast/predictions of a change in the atmospheric

parameters in time and space; 3) calculations in electronic computers.

The successful solution of an entire problem assumes the simultaneous realization of the problems comprising it.

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Now most successfully is solved, perhaps, the second problem. To this considerably contributes the work of the collective of the data processing center of SC AN USSR. The first and third tasks do not have material basis for resolution on contemporary standard of knowledge. The initial data on the atmospheric parameters which we now dispose of, are characterized by the essential deficiency/lacks the main thing from which - low three-dimensional/space and time/temporary density. In other words, the worldwide network of hydrometeorological stations is placed on planet very unevenly. More than two third Earth are occupied with oceans and seas, and the information about the atmospheric parameters above them are very scanty. Yes even on dry land the arrangement/position of stations far from perfection. It is clear, for example, that on the enormous spaces of Siberia it is not possible to create so dense a grid/network of weather stations as in the European part of the country.

Further. Basic part of the meteorological information to specialists give ground-based measurements. A quantity of information about the atmospheric parameters sharply decreases in proportion to increase in altitude. Finally, even ground-based measurements, despite, the apparent completeness, bring the data far not on all processes, which affect weather formation. As a rule, are not measured concentration and size of the particles of the aerosols, concentration of a series of the atmospheric gases, which absorb solar radiation.

The insufficient supply of material for successful solution of the third task is manifested in the fact that are absent the electronic computers with the high speed operation and the enormous memory. Discussion deals with tens of millions of actions per second and memories in millions of signs. Rapid development of electronic computational technology gives to us complete confidence, that in the near future we will have such machines. To much more complexly solve the task of the collection of information of the state of the atmosphere.

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The utilized at present methods of ground-based measurements and aerological sounding of the atmosphere virtually exhausted themselves and they cannot give the total characteristic of the meteorological parameters on planetary scale. The most widely used echo method of the atmosphere by the radiosondes, suspend/hung to the filled with hydrogen tank/balloons, gives to us the data on the pressure, the temperature, the wind and the humidity to height/altitudes approximately in 30 km, moreover the data on humidity are accurate only to the height/altitudes of 10-12 km. Maximum altitude radiosonde it reaches for 1.5-2.0 hours of the controlled by the wind flight.

The ceiling of aircraft sounding is still less. Furthermore, aircraft in flight agitates the atmosphere, which noticeably affects the results of measurements. The ceiling of the rocket sounding of the atmosphere completely can satisfy the necessity of practice. However, in this case it is necessary to consider effect on the results of the measurements of the disturbing action of rocket. Moreover rocket sounding is very expensive.

Consequently, the solution of the task of the collection of the initial data, necessary for reliable weather forecasting, is connected with the development of new methods of the study of the atmosphere. It is not possible to correctly predict the trend of development of atmospheric phenomena, without possessing reliable

infcrmation abcut their state at each given mcment of time.

Any of the new methods of study atmosphere must be remote, i.e., it must give informaticn during measurements at different distances frcm the utilized instrument. In order to obtain the necessary information, it is necessary tc simultaneously measure the atmospheric parameters on an entire planet.

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Sc, if we place stations at a distance of 300 km from each other, then in order to evenly cover with them entire surface of the Earth, them is necessarily more than 1,000,000. Each station simultaneously must measure several atmospheric parameters (as the minimum - temperature, pressure, force and direction of the wind, humidity) at least at 10 different height/altitudes. Thus, the volume of the cbtained infcrmaticn must contain tens of millions of values. Furthermore, the ceiling cf sounding must be brcught at least to 100 km.

Is develcp/processed at present a series of the methods of the remote sensing of different atmcspheric parameters: radar, laser, accustic and method, instituted on of the measurements of the spectral composition of the outgoing into Kosmos thermal

emission/radiation. Each of them has their advantages and disadvantages. However, great (no meanings) in laser sounding.

The prospect of the method of laser sounding is first of all defined by the diversity of the coupling effects of laser emission/radiation with the atmosphere as medium, with atmospheric gases, aerosols, turbulent heterogeneities. It is not less important that the easily attainable short duration of the sounding laser pulses provides fantastically high spatial resolution of the results of sounding, unthinkable with other methods. So, only by lasers it is possible to completely investigate the dynamics of cloud with the detailed check of the physical conditions of the very small volume of the medium where these processes occur. The high three-dimensional/space and time/temporary resolution of the results of sounding, the possibility of obtaining continuous profile of any atmospheric parameter in the predetermined direction, the rapidity of the solution of task, caused by the fact that the signal is spread with the speed of light and here, almost instantly is processed on high-speed electronic computer, the relative cheapness of investigation - thus those remarkable special feature/peculiarities of the method of the laser sounding which provide to it large future.

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The introduction of laser sounding into the worldwide network of hydrometeorological stations revolutionizes the methods of the study of the atmosphere. Is extremely promising the use of a laser probe of the atmosphere from onboard of artificial Earth satellites or lasting orbital stations. In this case the problem of data collection on the atmospheric parameters is solved on global scale.

The realization of the possibility of the wide application of lasers in communicating system, for the transmission of information, location, for the ultra-precise determination of distance of distant subjects, in locators for sounding of the atmosphere and so forth depends substantially on the knowledge of the phenomena of interaction of laser beam with the earth's atmosphere. It is possible to confidently say that precisely the atmosphere with its manifold properties, which are changed both in space and in time, most frequently project/emerges as judge, who are determining the fate of one or the other practical use of a laser. Therefore the study of the problem of interaction of laser emission/radiation with atmospheric has exclusively important value.

In 1956 three colleagues (including this author) of the laboratory of spectroscopy of Siberian physicotechnological institute with Tomsk university they began to investigate the laws governing the propagation of the electromagnetic waves of optical

range in the atmosphere. In 1960 in institute, was created the laboratory of infrared radiations. On its basis in 1962 in Tomsk university was opened the department of the optical-electronic instruments, and in 1969 was created the Institute of optics of the atmosphere of SO AN USSR.

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New scientific collective was yearly supplemented by graduates of Tomsk university, which began their work in laboratory from the third course. Quantitative growth of the collective was accompanied by the corresponding expansion of the emitted problems.

First was studied the integral (total) transparency of atmospheric boundary layer in the infrared region of the spectrum. It soon became it is clear that for explaining those or other values of the integral transparency of the atmosphere it is necessary to know the spectral transparency, which always depends on two basic components - absorption by atmospheric gases and scattering on atmospheric aerosols.

To the time of the appearance of lasers in our collective was investigated a series of laws governing of absorption and scattering of visible and infrared radiations in different narrow regions of the

spectrum. The basic results of work are generalized in author's monograph the "Transparency of the atmosphere for the visible and infrared rays", published by publishing house "Sovetskoe Radio" in 1966.

The creation of quantum generators and the possibility of their application in the communicating systems, transmission of information and so forth served as powerful/thick jerk/impulse to the studies of the laws governing the propagation of laser emission/radiation in the atmosphere, initiated into 1963. They became the new stage of our work whose success to a considerable degree was caused by the scientific luggage of the preceding/previous years.

Those leading in the institute of optics of the atmosphere of SO AN USSR, in the laboratory of infrared radiations of Siberian physiptechnical institute and in the department of the optical-electronic instruments of the works, dedicated to the propagation of laser emission, virtually cover all aspects of problem. Comprehensive experimental and theoretical studies connect the detailed study of the spectra of absorption of atmospheric gases, scattering of emission/radiation by aerosols (among other things by clouds, by mist/fogs, by mists, by fumes, by residue/settlings), effect of turbulence of the atmosphere on the structure of laser beams, nonlinear effects, which accompany the propagation of

powerful/thick emission/radiation in the atmosphere.

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In recent years in collective, appeared the new direction of investigations, connected with the use of lasers for the remote sensing of different atmospheric parameters.

In all investigations are considered the characteristics of lasers themselves - power, energy, spectrum, angle of divergence and the duration of emission/radiation, the diameter of beam and so forth and all possible meteorological conditions, such as only can be encountered at different height/altitudes in the atmosphere of entire planet.

On the basis of the conducted investigations it was possible to solve important estimation problem of the energy losses of laser emission/radiation, caused by absorption by atmospheric gases and by scattering by different aerosols. This made possible the predictions of the optimum parameters of lasers for solving one or the other task. Is carried out also a whole series of other works. To the generalization of the conducted investigations is dedicated author's second monograph "Propagation of the visible and infrared waves in the atmosphere", published by publishing house "Soviet radio" in 1970.

Remarkable special feature/peculiarity of the investigations of the Tomsk optics of the atmosphere - completeness of the solution of the problem of the propagation of laser emission/radiation in the atmosphere as a whole. Specifically, this approach, in our opinion, provides maximum effect not only in fundamental investigations, but also during the solution of applied problems, in particular, the laser sounding of the atmosphere. Last/latter task requires the goal-directed efforts of the large collective of the specialists in mathematics, spectroscopy, diffusion of light, quantum electronics, radio engineering, precision mechanics and optics, semiconductor technology and radio electronics. Equally necessary and important is the fruitful work of the experimenters and theorists, engineers and technologists.

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Development and introduction of the methods of the laser sounding of the atmosphere are especially urgent for such immense and thus far sparsely populated areas as Siberia.

The use of lasers in the atmosphere still only begins. It to a considerable degree depends on the state of the problem of the propagation of the laser emission/radiation in the atmosphere and on that, how rapidly available a knowledge will become the property of

the wide circle of people, called to solve the problems of the practical use of lasers in different equipment/devices, intended for a work in the atmosphere. Therefore the author undertook the attempt to write the popular science book, claiming to a strict special and popular presentation of the state of the problem of interaction of laser emission/radiation from terrestrial atmospheric and questions of the practical use of lasers in the atmosphere.

One should emphasize that the emission/radiation of the quantitative laws governing the propagation of laser emission/radiation in the atmosphere far exceeds the scope of the problem of the use of lasers in the atmosphere and of the connected with it practical mastery/adoption of the optical scale range of the electromagnetic waves. During this study automatically are obtained the valuable universal data on absorption, scattering and weakening of ultraviolet, visible, infrared and microwave radiation in the atmosphere. This information are extremely important for optics of the atmosphere, meteorology generally and satellite meteorology in particular. They are necessary for astrophysicists, astronomers, geodesists and specialists in infrared technology.

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Chapter One.

AMAZING PROPERTIES OF LASER RADIATION.

Depending on the substance of working medium/propellant, in which occurs the generation of energy, all lasers are divided into gas, solid-body, semiconductor and liquid ones. In each of these types of lasers, there are their subtypes with characteristic features.

Another classification of lasers is connected with the modes of their operation. Are distinguished the following conditions/modes: 1) continuous emission/radiation, 2) pulse emission/radiation in the conditions/mode of free generation, 3) pulse emission/radiation in the conditions/mode of the q-switching even 4) pulse emission/radiation in the conditions/mode of the synchronization of modes.

The pulsed operations of generation differ from each other duration, energy and power of momentum/impulse/pulses. During transition from pulse emission/radiation in the conditions/mode of

free generaticn to pulse emission/radiation in the conditions/mode of the synchronization of modes the duraticn cf pulses and energy they decrease, but power grow/rises. This is caused by the fact that the pulse duration decreases many times more than their energy.

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Laser emission/radiaticn possesses amazing properties: 1) giant power, 2) high monochrcmaticity, 3) coherence, 4) polarization, 5) small divergence, 6) enormous informativeness, 7) with the changing cver wide limits duration of the generatable pulse, 8) the possibility to change the wavelength of emissicn/radiation.

Let us note, however, that each laser possesses simultaneously these all properties, and for its one or the other practical application/use it is entirely not compulsory so that all these properties would be exhibited in one generator.

Radiated power of laser - ratio/relaticn to the emitted energy to the time of its emission/radiation [1].

FOOTNOTE [1]. As the units of power measurement serve watts, kilowatts, megawatts and gigawatts (1 gigawatt = 1,000,000,000 W). ENDFOOTNOTE.

working in continuous duty laser emits constant power. In pulsed operation for the time of the emission impulse of laser, its power varies from 0 to maximum value and again to 0. In this case it is possible to speak about average/mean and peak power. Average/mean power is equal to total energy of momentum/impulse/pulse, divided into its duration; peak is determined by the ratio/relation to energy in the maximum of momentum/impulse/pulse to the time interval, during which this maximum is emitted.

The radiated power of different lasers is included in extremely broad band. Maximum power possess solid-body lasers, workers in the conditions/mode of generation with the q-switching and, in particular, in the conditions/mode of the synchronization of modes. In the latter case the momentum/impulse/pulses with duration about a trillionth of a second possess the power approximately 1,000,000,000 W, into hundred and thousands of times exceeding the power of large/coarsest electrical stations. In the conditions/mode of the q-switching, solid-body lasers capable of radiating power in ten and hundreds of million kilowatts with the momentum/impulse/pulse, which is continued ten billionth fractions of a second.

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In the continuous duty of generation, maximum radiated power is

obtained in gas lasers on carbon dioxide. This power is determined by the length of discharge tube, besides discharge can simultaneously go in the series of tubes. The power of such lasers several kilowatt - already passed stage.

The creation of lasers made it possible to reveal/detect, to investigate and to utilize the new phenomena in the atmosphere, connected with the so-called nonlinear effects. One of them, for example, consists in the fact that the specific radiated power causes by the electrical sample/test of air and leads to the education/formation of plasma. This phenomenon is an insurmountable barrier for transportation through the atmosphere of high-power optical radiation.

A whole series of the most interesting phenomena appears at the power smaller than the threshold value for the breakdown of air. These are, first of all, the illumination of the atmosphere and self focusing laser beam. With the defined the power molecule of atmospheric gases cannot intensely absorb emission/radiation as at usual, low power. The atmosphere is cleared, its transparency substantially grow/rises. On the other hand, the propagation of powerful/thick optical radiation in the atmosphere changes the refracting properties of the channel itself through which it occurs this propagation. In this case the channel of laser beam is converted

into an original waveguide.

Powerful/thick laser beam in state to thread the large ones of atmospheric depths. So, in the cloudless atmosphere is feasible the method of laser emission/radiation at any distance of direct/straight visibility between the source and the receiver.

Monochromaticity of emission/radiation - ratio of the emitted band of frequencies (or wavelengths) to the frequency (or wavelength) of emission/radiation, this arranged/located in center band. For example, when we listen to the program of radio transmissions, announcers call only the wavelengths of broadcasting service, but are not called the band of the emitted wavelengths. But precisely because each station emits not one wavelength, but whole band, in ether/ester it becomes tight, and this of closenesses we distinctly feel, when we attempt to catch any station.

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The higher the monochromaticity of radiated waves, the more the transmitting stations it is possible to place on one and the same wave band so that they would not interfere with each other. Thus, it is possible to say that the monochromaticity of radiation is characterized by the narrowness of that spectral interval (wave

band), in which are placed all the generated by this source frequencies or the wavelengths of emission/radiation.

The high monochromaticity of the laser emission/radiation (it still it is possible to call/name the narrowness of its spectrum) special is inherent in gas lasers. So, the most widespread gas laser on the mixture of helium with neon, which radiates in the red field of visible spectrum wavelength 6328 Å, in the usual conditions/mode of generation has width of the spectrum the approximately equal to 0.02 Å. The width of radiation spectrum can be decreased many times with the aid of special equipment/devices.

The radiation spectra of solid-body, semiconductor and liquid lasers usually occupy range by width from tenths to tens of Angstrom. However, with the aid of special equipment/devices and they it is possible to throttle/taper and to bring to the hundredth and thousanths of Angstrom.

High monochromaticity of laser emission/radiation, the reason for its fantastic spectral density (energy density to single spectral interval, for example, to interval in wide in 1 Å).. The power of the first laser on the crystal of the ruby, created into 1960 in the conditions/mode of free generation was approximately 10 kW.

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At this small power (in comparison with contemporary high-power generators) its spectral brightness was almost 1,000,000 times more than in the Sun. This means that for the time of emission impulse in spectral interval width in several tenths of Angstrom in area of wavelength 6943 Å laser emission were 1,000,000 times brighter than Solar radiation in the same narrow spectral interval.

The width of the radiation spectra of lasers is close to the width of the spectral lines of the absorption of atmospheric gases. Both radiation spectra and lines of absorption sharply depends on wavelength. Within the limits of the center section of the lines of absorption, the absorption coefficient can be changed on several orders. Even to larger degree is changed brightness coefficient within the limits of the radiation spectrum of laser. If emission/radiation line falls into the center section of the line of absorption, shift/shear of one relative to another to the value, measured by the hundredth and even thousandths of kayser, can substantially change the absorption of laser emission/radiation in the atmosphere. Therefore it is very important to know the position of the lines of emission/radiation and absorption with an accuracy to the thousandths of kayser.

In the unique spectroscopic instrumentations, with the aid of which, until now, were investigated the spectra of absorption of atmospheric gases, resolution did not exceed several hundredths of kayser. Consequently, entire accumulated material about the spectra of absorption of atmospheric gases does not virtually befit for the quantitative estimation of fading laser emission/radiation in the atmosphere.

Development of laser technology assigned before optics of the atmosphere the completely new and very difficult mission: to develop such methods of the experimental and theoretical study of the spectra of absorption of atmospheric gases which would make it possible to obtain these spectra with the complete resolution of fine structure with the complete resolution of the fine structure of lines.

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It is necessary in this case so that the position of the centers of lines in the spectrum would be determined with an accuracy to the thousanths of kayser.

Narrowness and definition of the lines of the absorption of atmospheric gases and lines of laser emission explains the interesting fact of an extremely powerful change of absorbing the

laser emission/radiation in the atmosphere with an insignificant difference in the conditions of generation as this was reveal/detected in ruby generator, capable of changing wavelength during a change in the temperature of the working medium/propellant of the crystal of ruby under the action of absorbed energy of the lamp of pumping.

Lasers with narrow and stabilized along the length of wave lines are extremely promising for the remote sensing of the concentration of any atmospheric gas.

The coherence of laser emission/radiation is caused by its nature and is obtained virtually automatically, while in all usual sources of optical radiation (incandescent lamp, gas-discharge sources, electric arcs, solar radiation, etc.) compulsorily is generated incoherent emission/radiation.

Both in laser and in usual thermal or gas-discharge sources "glow" separate atoms or molecules. The emission/radiation of each atom and each molecule it is possible to consider coherent, i.e., representing itself correct wave with the clearly following after each other maximums and the minimums. In usual sources the generation of atoms or molecules occurs chaotically, mismatched, by virtue of which the resulting emission/radiation by nature itself cannot be

correct wave. Meanwhile in lasers, the emission/radiation of the totality of atoms or molecules occurs as on command/crew, it is simultaneous.

Therefore the waves, emitted by atoms and molecules, being combined, give powerful/thick correct wave.

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The coherent properties of laser emission/radiation can be used in the communication lines, in holography, for example for obtaining the volumetric images of invisible ones by the eye of the particles of the atmospheric aerosols, during the ultra-precise determination of distance of the distant object/subjects and in a whole series of other investigations, the accuracy of measurements in which is compared with the wavelength of emission/radiation (microns into the tenths of microns).

Polarization of emission/radiation. World/light can be linearly polarized, elliptically polarized, polarized on a circle or not polarized (they are natural). Any light wave has electromagnetic nature, speaking in other words, it is the spread with the speed of light electromagnetic vibration in which the vectors of the intensity/strength of variable electrical and magnetic fields are

perpendicular to each other and direction of propagation of wave. If during the propagation of wave the plane of vibration of any of the vectors remains constant/invariable, then in this case we deal with the linearly polarized radiation; but if by any of the vectors continuously is changed plane of vibration, describing ellipse or circumference, then available elliptical or circular polarization of light. For a natural (not polarized) world/light the vectors of the intensity/strength of electrical and magnetic fields do not have the preferred direction of vibrations.

Nonpolarized emission/radiation - characteristic property of all usual sources of light (thermal, gas-discharge, etc.). The distinctive special feature/peculiarity of laser sources, on the contrary, the polarization of emission/radiation, form and degree of which depend on the type of laser and mode of its operation. This fact is extremely important, and it can be widely used during the study of scattering of light in the atmosphere. Different aerosol particles differently affect polarized radiation.

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Consequently, there appears the possibility of emit/radiating different characteristics of aerosols (concentration, form, sizes of particles, their chemical composition) on the basis of the

investigation of the depolarization of radiation during its propagation in medium. When emission/radiation accepts the instrument, which passes polarized light and not passing not polarized, it is possible to increase the distance of the reception of indicating lights, decreasing the ratio of useful signal to interferences.

Divergence of emission/radiation. Any laser emits the emission/radiation which can be characterized by the initial diameter of light beam and the angle of its divergence. This beam is the divergent cone. The lesser the angle between the axis of cone and its generatrix, the greater the distance it is possible to transmit optical signals.

Being small by nature itself, the divergence of laser emission/radiation with the aid of optical systems (telescopes) in principle can be decreased to the theoretically possible limit, caused by diffraction. It is known that, after meeting on its path an obstacle, the light wave, as if attempting to bridge it, changes initial direction. This "folding" of waves exists a phenomenon of diffraction. During the propagation of laser emission/radiation in optical system (telescope) as the obstructions for wave project/emerge the edges of optical cell/elements (lenses, mirrors, etc.).

The divergence, caused by diffraction, is proportional to the wavelength of emission/radiation and it is inversely proportional to the diameter of optical objective or mirror, which forms beam of light. The wavelengths of the emission/radiation of the overwhelming majority of lasers are included within limits from 0.3 to 11 μ. With the diameter of objective in 20 cm, the angle of diffraction divergence for the interval of wavelengths 0.3-11 μ is included within limits approximately from 0.4 to 14 seconds of arc. Let us note that at the angle of divergence in 1 second of arc the light ray increases its diameter in all by 0.5 cm during propagation by distance 1 km. Thus, in practice with the aid of lasers it is possible to obtain virtually parallel beam of light.

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Small divergence of laser emission/radiation provides the possibility of the transportation of luminous energy up to large distances, which is especially important for the work of all laser equipment/devices (communicating system, the transmission of information, the ultra-precise determination of distance, location, remote sensing of the atmosphere, etc.).

The informativeness of emission/radiation, or the ability of laser to transfer to distance diverse information, much exceeds the informativeness of the electromagnetic waves of radio-frequency range. Is explained this by the enormous emission frequency of lasers. In fact, if the emission frequencies of lasers are equal to approximately 10^{14}-10^{15} vibrations per second, then in high-frequency radio waves they are millions times less. But quantity of information, which capable of transferring the electromagnetic wave, depends precisely on the frequency of its emission/radiation.

The potential possibilities of the transmission of information with the aid of laser beam are virtually infinite. It is calculated, that the theoretically laser beam can simultaneously transfer 100,000 television programs or 100,000,000 telephone conversations. True, a quantity of transferred by laser beam information in many respects depends on the development of technology of input and output of information. Essential effect have propagation conditions of the emission/radiations in the atmosphere, without detailed investigation of which it is difficult to speak about the effectiveness of the operation of the communicating systems, transmission of the information of signaling, etc.

The duration of the pulse of laser emission/radiation changes in dependence on the type of generator and conditions/mode of generation

within very considerable limits. In work in the conditions/modes of free generation, q-switching and synchronization of modes the duration of emission impulse measures in micro-, nano- and picosecond or, correspondingly, in the millionths, billionths and trillionths of a second.

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Virtually it is possible to obtain the momentum/impulse/pulse of any duration - from prolonged to subpicosecond (order of a fraction of picosecond).

The extremely short durations of laser pulses create the possibility of applying the lasers for the diverse scientific investigations of the structure of matter. it is known that the duration of the processes, which occur in atoms and molecules generally and during their diverse interactions, is calculated by ten-billionths and more fractions of a second. Thus, with the aid of the momentum/impulse/pulses of picosecond and nanosecond duration scientists can study the mechanisms of diverse phenomena of microcosm. Figuratively speaking, sounding microcosm by supershort laser pulses - this the conversation of man with atoms and molecules in their inherent language.

The laws governing the propagation of supershort light momentum/impulse/pulses in the atmosphere must considerably differ from the laws governing the propagation of continuous or quasi-continuous emission/radiation (pulse duration much more than the duration of the process of changing energy in atoms and molecules). The study of these laws is of great scientific interest and, undoubtedly, is created basis for their practical use. Even now, for example, it is known that during the propagation of the light momentum/impulse/pulses of midget duration the atmosphere capable of being cleared.

It is clear also, that the use of supershort laser pulses for sounding the atmosphere will ensure fantastic spatial resolution of its results, since the latter is determined by the path length of momentum/impulse/pulse in the atmosphere. It is not difficult to calculate, that, being spread with the speed of light - 300000 km/s, momentum/impulse/pulse, as duration into nanosecond, passes paths, equal a total of 30 cm.

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Change in the wavelength of emission/radiation. Wavelength of laser emission as any other source, one of the main things of its characteristic. In this case, one ought not to forget that in reality

the laser emits the set of wavelengths or the emission band whose center is conventionally designated as the wavelength of source.

A quantity of wavelengths of laser emission to a considerable degree determines their possible application/use. Certainly, the most favorable conditions for using the lasers will be created when entire optical wave band will be overlapped by their emission/radiation. Completely it is clear that we this will never attain, if we go on the path of the set of the various lengths of the emission/radiation of different lasers. In fact, in order to overlap only very narrow section of optical wave band, corresponding to the visible region of the spectrum (approximately from 0.4 to 0.76 μ, or between 25,000 and 13,080 cm^{-1}), laser emissions with bands 0.01 cm^{-1}, it is necessarily more than 1,000,000 lasers. Furthermore, it is virtually impossible to fit the work substances of the lasers which would ensure the desirable set of the wavelengths of emission/radiation. Therefore it is extremely important to force lasers to emit the needed by science and practice wavelengths and to learn to control them.

A change in the wavelength of laser emission can be realized by different methods depending on the type of generator and range of rearrangement.

Under the influence on the gas lasers of external electrical or

magnetic fields, the wavelength of their emission/radiation is displaced proportional to the strength of field. Thus it is possible to displace wavelength to value to 1-2 cm^{-1}. This it is completely sufficient in order, for example, to descend from the center section of the line of the absorption of atmospheric gas and to hit the section between lines with small absorption.

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On the other hand, if without the effect of field the line of the emission/radiation of gas laser coincided with the line of absorption, then the displacement of wavelength on 1-2 cm^{-1} allows during a gradual change in the strength of field to investigate the duct/contour of the line of absorption. If emission/radiation line is much already the line of absorption, which is technically completely attainable, then the duct/contour of the line of absorption is not distorted.

It is well known that on the duct/contour of the line of absorption most distinctly are exhibited different factors, which affect the absorptivity of the substance (for example, pressure, temperature, concentration of the absorbing molecules, etc.) being investigated. Therefore recording the undistorted duct/contour of the line of absorption indicates the creation of the new ideal method of

emit/radiating the phenomena of microcosm.

There is a series of methods of changing the wavelength laser emission within considerably wider limits, than during the use of electrical and magnetic fields. So, with the transmission of powerful/thick laser emission/radiation through the so-called nonlinear crystal it is possible to obtain emission/radiation with doubled, tripled and so forth by frequency (second third and so forth of the harmonic of fundamental emission frequency). For example, fundamental emission frequencies in the most widespread solid-body generators on ruby and on glass correspond to wavelengths 0.69 (red region of the visible scale range of the electromagnetic waves) and to 1.06 μ (nearest infrared region). The second harmonics of these generators are emitted at wavelengths 0.349 (near ultraviolet region) and 0.53 μ (green region of the visible region).

The very promising method of the rearrangement of the emission frequency of lasers is the method of parametric generation. Its essence in the fact that on leaving from nonlinear crystal the powerful/thick optical radiation proves to be consisting of two frequencies, sum of which compose the frequency of incident radiation. The values of frequencies change in dependence on the position of optical crystal index.

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Turning mechanically axis together with crystal or changing its position in a some other manner, it is possible at the output of crystal to obtain the continuously changing emission frequency. With the aid of this method it was possible to attain the rearrangement of the wavelength of the emission/radiation of generators on ruby and on glass with neodymium in the interval of several thousand Angstrom.

Are known other methods of the rearrangement of the wavelength of emission/radiation, including making it possible to produce rearrangement during one momentum/impulse/pulse.

Rearrangement the wavelength of laser emission/radiation has enormous practical value. First of all there is in form creation of laser from the defined, predetermined by wavelength of emission/radiation, is in the best way propagating in the atmosphere as the medium, which consists of the absorbing gases, aerosol particles and turbulent heterogeneities.

Rearrangement of the wavelength of emission/radiation - necessary condition during the development of the laser spectrometers, intended to give to the researchers the completely allowed spectra of the absorption of different substances in gas

phase. Specifically, in gas phase of substance, have complex line spectrums of ten and even hundreds of thousands of lines. Finally, the rearrangement of emission frequency over a wide range of wavelengths will make it possible to utilize lasers for the investigation of liquid-water content, concentration of particles and their distribution in clouds, mist/fogs, mists, precipitation and other atmospheric aerosols.

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Chapter Two.

LASER BEAM IN ATMOSPHERIC GASES.

The gaseous envelope of the Earth.

The solar radiation, which continuously enters our planet, source of life on the Earth. It serves as the main factor of weather formation.

Scientists have long gotten to know the qualitative picture of the processes of weather formation and they unanimously consider that they mainly depend on interaction of solar radiation with atmosphere and surface of the Earth. Such important characteristics of weather as the temperature, the pressure, the wind, the humidity, cloudiness, are connected with the fact that the quantity of solar energy passes different layers of the atmosphere on the way to our planet, what quantity of reached the Earth energy will be absorbed by it, how much

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the earth's surface of energy reflected will remain in the atmosphere and how much forever will leave into outer space.

The surface of the Earth, reaches the significant part of solar radiation. Heated by the Sun the Earth itself becomes radiation source. And here we encounter the curious phenomenon: emitted by planet energy seemingly it is detained, "deposits" in gases of the atmosphere. It emerges, the atmosphere plays the role of magic blanket: it relatively freely passes heat in one direction - to our planet it detains it - in reverse/inverse.

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The quantitative picture of interaction of solar radiation with atmosphere and surface of the Earth is extremely complex. Absorbing properties of the atmosphere depend on many reasons. The absorbing solar radiation atmospheric gases have exclusively the complex structure of the spectra. The estimation of the absorption of laser emission/radiation is possible only on the basis of the high-precision knowledge of the spectra of absorption of atmospheric gases, the clear representation of the gas composition of the atmosphere, its temperature, pressure, about their change in time and space.

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The atmosphere consists mainly of nitrogen, oxygen and argon. The average/mean volume concentration of nitrogen in the lower layer of the atmosphere is equal to 78.084o/o, oxygen 20.946 argon $9.34\cdot10^{-1}$o/o. At height/altitudes to 95-110 km, these gases are well agitated, but above they are distributed depending on molecular weights.

Figure 1 shows the distribution of different atmospheric gases for the interval of the height/altitudes of 20-130 km. Besides those indicated in figure, the atmosphere contains the traces of many other gases, which do not have any essential effect on the energy absorption of solar radiation.

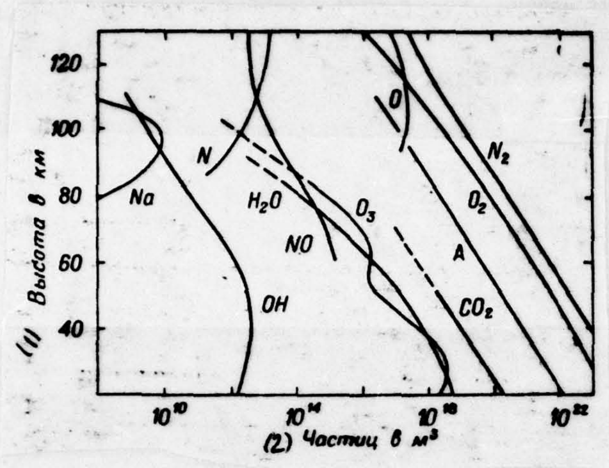

Fig. 1. Distribution of some atmospheric gases in the interval of the height/altitudes of 20-130 km.

Key: (1). Height/altitude in km. (2). Particles in m^3.

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Atmospheric pressure very rapidly decreases with height/altitude and very weakly it changes in time at base altitude, at least in the lower 30-kilometer layer of the atmosphere. On the surface of the Earth, the pressure is equal approximately to 1 atm., at height/altitude 10, 20, 30, 40 and 100 km it decreases, respectively into 4, 20, 80, 350 and 1,000,000 times. Consequently, bulk of the atmosphere is concentrated in lower 30-kilometer layer.

Mean pressure at the level of sea to scale of terrestial globe is equal to 1013 mbr. Divergences from the average value of pressure are found approximately within limits by ±3o/o (980-1040 mbr), and they can be completely disregarded in comparison with the change in the pressure with height/altitude, which can be considered virtually identical for all areas of terrestial globe.

Very uniquely behaves the temperature of the atmosphere. Its values on the surface of the Earth at each point depend on the time of days and season, but at one and the same moment of time, - from the coordinates of point. The dependence of temperature on height/altitude (or the elevation profile of temperature), strictly speaking, it is changed in the course of time. However, if we examine vertical profiles of temperature - time-averaged or by geographical areas, then clearly are outlined the layers of the atmospheres within limits of which the temperature decreases with height/altitude or, on the contrary, grow/rises.

The quite lower layer, in which mean temperature decreases with height/altitude, is conventionally designated as the troposphere. Its thickness depends on the season and latitude of locality. In tropical regions it is equal to 16-18, in polar ones - 7-10 km. The following

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or height/altitude layer of the atmosphere is called the stratosphere.

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It stretches approximately to the height/altitude of 50 km. Here temperature first slowly, and then rapidly is raised in proportion to lift upward.

In mesosphere, at height/altitudes approximately from 50 to 80-90 km, the temperature with height/altitude is reduced. In the following layer - thermosphere - is observed first a sharp increase of temperature with an altitude (approximately to 200 km), then - slower (in the interval of the height/altitudes of 200-300 km), and finally on high altitudes it heaves very slowly.

Between the troposphere and the stratosphere, the stratosphere and the mesosphere, the mesosphere and the thermosphere, are arrange/located fine/thin intermediate layers, tropopause, stratopause and mesopause, in which the signs of temperature lapses change.

The average values of temperature at the level of the ocean in areas of tropopause, stratopause and mesopause for 45° of north

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latitude, according to the standard model of the atmosphere, are equal respectively: 15; -56; -2 and -92°C. At height/altitudes 200, 300 and 700 km mean temperature reaches 963, 1159 and 1235°C.

Besides the examined above layers of the atmosphere, which have the character of planetary education/formation, in the atmosphere can be outlined the small/finer layers of the so-called temperature inversions, in which the elevation profile of the temperature differs in sign from average elevation profile. Most frequently inversion layers are encountered in the troposphere and, in particular, in its quite lower layer with a thickness of 2-3 km. In inversion tropospheric layers the temperature is not reduced, but it is raised with height/altitude.

The humidity of the atmosphere, connected with the concentration of water vapor, plays enormous role in all processes of converting energy the Earth. From a quantity of water vapor in the atmosphere, depends substantially the heat balance of our planet, processes climate and weather formation, and also possibility of applying different technical equipment, which use sources of optical radiation, including lasers.

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Water vapor - main absorber of solar radiation on the way to the Earth. The abundance of lines in the spectrum of absorption of water vapor creates the frequently encountered obstructions on the way of laser emissions at different wavelengths.

Water vapor - most variable in time and space gas component of the atmosphere. For the characteristic of air humidity, the scientists introduced whole series of unity: 1) the absolute humidity, characterizing a quantity of water vapor in grams to cubic meter; 2) the vapor pressure or is pressure, expressed usually in millimeters of mercury or in millibars; 3) the relative humidity, which is the measured in percentages ratio of water vapor pressure, which was being contained in air, to pressure of saturated steam at this temperature; 4) specific humidity - mass of water vapor in the unit of the mass of humid air (usually it is measured in grams to kilogram); 5) the mixing ratio, which is the mass of water vapor in unity, the masses of dry air; 6) the precipitated layer of water, which characterizes the thickness of the layer of water, which will be obtained, if we completely condense by the water vapor in this thickness of the atmosphere; 7) the point of dew - temperature of the air, cooled to the state of the saturation of that locating in it of vapor.

In Table 1 are provided the values of air humidity at the level

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of sea at different temperature.

Pressure of saturated steam is virtually the maximum water vapor pressure at this temperature, which corresponds to the value of the relative humidity, equal to 100o/o. In the atmosphere hardly ever relative the humidity is close to 100o/o.

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Therefore in the majority of the cases, water vapor pressure is less than is shown in table at the corresponding temperatures. Close to 100o/o relative humidity is observed when according to one or the other reasons in the atmosphere it is sufficient moisture for achievement of the state of saturation. This can be, for example, in immediate proximity from water surface or during a temperature decrease to the dew point, as it occurs during formation of clouds and fogs. Very formation of clouds and fogs is the condensation of water vapor. Is condensed first of all that part of the mass of water vapor, which is excess in comparison with pressure of saturated steam. Relative humidity in clouds and mist/fogs is frequently close to 100o/o. Depending on conditions in cloud and stage of its development, it can be less, but virtually never there is more than 100o/o.

From table it is evident that the maximum water vapor pressure at the level of sea in the range of temperatures from -20 to +50°C comprises approximately from 0.1 to 12o/o of total pressure, and 1 m^3 of air contains from 1 to 83 g of water.

During the study of the energy absorption of optical waves, frequently is utilized the concept of the precipitated layer of water.

Table 1. Characteristic of air humidity at the level of sea at different temperatures.

(1) Температура, °C	(2) Давление насыщенного пара, мбр	(3) Абсолютная влажность, г/м³	(4) Удельная влажность, г/кг	(5) Отношение смеси, г/кг
—20	1,254	1,073	0,780	0,781
—10	2,863	2,857	1,782	1,786
0	6,108	4,845	3,808	3,822
10	12,270	9,39	7,67	7,73
20	23,37	17,27	14,67	14,89
30	42,43	30,33	26,82	27,56
40	73,78	65,30	47,20	49,54
50	123,40	82,76	80,51	87,56

Key: (1). Temperature, °C. (2). Pressure of saturated steam, mbr. (3). Absolute humidity, g/m³. (4). Specific humidity, g/kg. (5). Mixing ratio, g/kg.

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The value of the precipitated layer of water of the uniform thickness of the atmosphere in millimeters on 1 km is equal to the value of the absolute humidity, expressed in the grams to of 1 m³. So, with the humidity 10 g to of 1 m³ the kilometer layer of the atmosphere contains 10 mm of the precipitated water.

The concentration of water vapor in the atmosphere is more

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variable than temperature, since during a change in the temperature pressure the saturated steam changes considerably faster than according to the law of proportionality. Furthermore, the interval of the possible values of absolute humidity is substantially wider than the interval of the variation in the pressure of saturated steam. It is possible to say that each concrete/specific/actual measurement of the elevation profile of humidity is unique. However, the course of average vertical profile of humidity at present is sufficiently well studied, especially in the troposphere.

To the troposphere absolute humidity, as total pressure, with height/altitude decreases exponentially, but it is considerably faster than total pressure. Average specific humidity decreases in range from the sea level to tropopause hundreds times.

The results of the measurements of humidity in the lower stratosphere (approximately to 30 km of height/altitude), carried out by different researchers, are contradictory. In some cases the specific humidity either virtually is unchanged with height/altitude, or it decreases, in others - is reveal/detected, a sufficiently considerable increase in it from tropopause to the height/altitude of 30 km. In connection with this, arose two models of the stratosphere - "dry" and "humid". It is obvious, the difference as results is explained by the fact that the measurements were conducted under

ronidertical conditions.

Establish/installed the presence of water vapor in upper stratosphere and mesosphere, but about its quantity as yet it is not possible to make any conclusions in connection with the extremely limited data.

The origin of the molecules of ozone, which consist of three atoms of oxygen, is connected with short-wave ultraviolet solar radiation.

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This radiation capable of splitting the usual biatomic molecule of oxygen into its comprising atoms which go for the education/formation of the molecules of ozone. At the height/altitudes of 60-70 km, ozone concentration is very small, since is small the concentration of molecular oxygen which serves as "raw material" for the formation of ozone. In proportion to the penetration of radiation into the depths of the air ocean together with an increase in the concentration of molecular oxygen increases a quantity of split to atoms molecules and it is simultaneous - ozone concentration. Approximately at the height/altitude of 20-30 km, it reaches maximum value, and then sharply decreases, despite the the fact that molecular oxygen at low

altitudes is much more. The reason for this phenomenon is explained sufficiently simply. The lion portion of the short-wave ultraviolet solar radiation, capable of splitting the molecules of oxygen, is expend/consumed at the height/altitudes of 20-30 km.

Let us note that ozone layer in the atmosphere - this is the distinct natural filter, which delays that part of the ultraviolet radiation of the Sun whose penetration would make impossible a life in its contemporary form.

SPECTRA OF ABSORPTION OF ATMOSPHERIC GASES.

According to the laws of quantum mechanics, the atoms and molecule are capable of absorbing or of emitting only completely determined to portion or quanta of energy. In this case, each atom and each molecule of one or the other substance absorb or emit their inherent ones, only for them the characteristic sets of the quanta of energy, or the sets of frequencies, since quantum energy is proportional to the frequency of absorption or emission/radiation. These sets also create the spectra of absorption or emission/radiation of substance. The ability of each substance to have its inherent spectrum of absorption or emission/radiation is the basis of one of the most powerful/thick contemporary methods of the quantitative and qualitative analysis of substances - spectral analysis.

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Atmospheric gases also have both the absorption spectra and radiation spectra. In the origin of the spectra of all substances, is observed a series of general laws.

First of all, the atoms have the so-called electron spectra of absorption. The origin of this name is connected with the fact that during absorption by the atom of the specific quantum of energy one of the peripheral electrons of atom jumps to more distant from nucleus orbit. The greater energy or frequency of quantum, that in more distant orbit jumps electron in atom. In the extreme case, when the portion of the absorbed by atom energy is equal or more than to the binding energy of peripheral electron with nucleus, occurs the ionization of atom (complete electron detachment from atom). Thus, the quantum absorption of energy by atom is equivalent to a change in the energy of its electron shell.

Molecules have electronic, vibrational and rotational spectra. The origin of the electron spectra of molecules is analogous with the origin of the spectra of atoms. The vibrational and rotational spectra of molecules appear during the charge in the vibrational and

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rotational energy which just as a change in the electron energy, occurs irregularly. The quantity of different in frequency quanta of vibraticral or rotational energy, which the molecule capable of absorbing, depends on the type of molecule, its complexity, structure.

Energy of electron transitions is measured by whole electron-volts, is oscillatory energy - by tenths and hundredths, and rotary - by tenths and hundredths, and rotational energy - by thousandths and ten thousandths of electron-volt.

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In accordance with the value of the quanta of energy, the electron spectra of atoms and molecules occupy the ultraviolet and visible part of the spectrum of the scale of electromagnetic waves, the vibrational spectra of molecules - close infrared region and rotary - distant infrared and microwave regions. As is known, visible range of the spectrum occupies the range of wavelengths approximately from 4000 to 7600 Å (or from 0.4 to 0.76 μ), ultraviolet from 4000 Å to X-ray emission/radiation, infrared from 0.76 μ to hundreds of microns and microwave - from hundreds of microns to centimeters.

The spectra of absorption of substance in practice are obtained

as the result of the energy absorption by an enormous quantity of molecules. Under whatever conditions occurred the process of the energy absorption by molecules, they are always distributed on the levels of electronic, vibrational and rotational energy. Each molecule at the given instant has the specific value of electronic, vibrational and rotational energy. Absorbed energy can go to an increase electronic, oscillatory, either rotary or it is simultaneous two any, or all three forms of energy. This depends on what portion of energy was absorbed by molecule. As a result it proves to be that if we record electron spectrum, then we obtain in reality the electron vibrational-rotational, during recording of the vibrational spectrum - vibrational-rotational spectrum, and only rotary can be recorded in pure form. In practice for simplicity the electron - vibrational-rotational spectrum is conventionally designated as simply electronic, and oscillatory-rotary-oscillatory.

It is electronic - oscillatorily - rotational spectrum is the series of spectrum bands. Each change in the electron energy, i.e., each electron transition, is accompanied, generally speaking, by entire possible totality of vibrational transitions in molecule. In turn, to each vibrational transition corresponds entire/all possible totality of rotary transitions. Figure 2 schematically depicts the electron vibrational-rotational spectrum of molecule.

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The distances between electronic, oscillatory and rotary transitions in molecules cf each substance are different. Under the actual conditicns are cbserved the overlaps of separate bands, strongly complicating the spectrum and its interpretation.

Analogously is matter alsc with the vibrational-rotational spectrum of absorption of molecules. It alsc banded, besides band frequently overlap. The concrete/specific/actual form of the spectrum depends cn the structure cf molecule. The mcre atoms contains molecule, the greater in it the types of vibrations, the richer the vibrational spectrum. The rctary structure cf electronic, vibrational and purely rctational spectra also depends substantially on the type cf molecules. All mclecules frcm the pcint cf view of rotational energy can be divided cn: 1) linear, 2) the type of spherical gyroscope, 3) the type cf symmetrical gyroscope even 4) the type of asymmetric gyroscope.

The division cf molecules according to their rotary properties is instituted on difference in the values cf principal moments of inertia. In the linear molecule two principal mcments of inertia relative to the axes, perpendicular to the axis of molecule, they are equal tc each other, and the third is equal to 0 (all atoms are

located on the third, principal rotational axis). In molecules of the type of spherical gyroscope, all principal moments of inertia are equal to each other.

Fig. 2. Diagrammatic representation of the electron vibrational-rotational spectrum of molecule. Roman numerals designated the frequencies of electron transitions; numerals 1, 2, 3 and so forth designate the frequencies of the vibrational transitions, with each of which is connected the palisade of rotary transitions.

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Molecules of the type of symmetrical gyroscope have two equal to each other principal moments of inertia, but the third is not equal to 0 and differs from first two. Finally, in molecules of the type of asymmetric gyroscope all three principal moments of inertia different and are different from 0.

Simplest rotary structure of the spectra in linear molecules, while most complex - in molecules of the type of asymmetric gyroscope. Among atmospheric gases the linear molecules have: carbon dioxide, nitrogen oxides, carbon monoxide, oxygen and nitrogen. Methane has a molecule of the type of spherical gyroscope, in water

vapcr, czone and heavy water - type of asymmetric gyroscope. Not some cf atmcspheric gases, which are present in the atmosphere on planetary scale, are molecules cf the type cf symmetrical gyroscope.

INTENSITY OF BANDS AND SPECTRAL LINES.

The spectra of the molecules of different substances are characterized by not cnly structure, but also intensity of the absorption bands and of their comprising lines. Some substances possess exclusively intense bands and lines of absorption, others, on the contrary, very weakly absorb emission/radiation. In the spectrum cf absorption of one and of the same substance, the intensity of different bands and lines can sharply differ.

In cne and the same substance the most intense bands and lines must be observed, when in their education/formation participates a maximum quantity of molecules. Under normal conditions the overwhelming majority of molecules is located in normal, unexcited, cr basic, state. Therefore, are mcst intense the absorption bands, obtained as a result of transitions of molecules from basic state to the nearest excited. The higher excited state, i.e., the greater quantum energy, the lesser the probability of its absorption by molecule. This law is characteristic for electronic, oscillatory and rotary transitions.

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However, the interpretation of the spectra of different substances is strongly hinder/hampered by the overlapping of the bands of different intensity.

The intensity of bands and lines of the absorption of the spectra of different substances can differ on many orders, which is caused by their different absorptivity in the appropriate wavelength ranges.

The intensity of each line of absorption - this is its individual characteristic. The intensities of all lines sufficiently complex depend on pressure and temperature.

Extremely large range of line intensities one and the same and different atmospheric gases together with the sharply pronounced lined structure of their spectra - main reason for the extremely high selectivity (critical dependence on wavelength) of the absorption of optical radiation in the atmosphere. Selectivity, on one hand, is exhibited in constant/invariable sharp bursts and incidence/drops in the absorbing properties of the atmosphere, as soon as we prove to be

in area of any of the numerous lines of absorption. On the other hand, the maximum values of the absorption coefficients in the centers of individual lines are changed from one line to the next within the extremely wide limits: in ten, hundred, thousand, million or more times.

FORM OF THE CONTOUR OF THE LINES OF ABSORPTION.

As a result of the interaction of molecules with each other, their chaotic thermal agitation also along a series of other reasons the energy levels are displaced in comparison with their position in the isolated/insulated molecules. The amount of this displacement in different molecules is different. Therefore, during the transition of molecules from one energy level to another, they absorb not one monochromatic emission frequency, but the whole set of frequencies.

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If we taking into account this determine the dependence of the absorptivity of molecules on frequency for this energy transition or the dependence of the absorption coefficient on frequency, then we will obtain the duct/contour of the line of absorption (Fig. 3).

Frequency ν_0 characterizes the center of the line of

absorption. This is that frequency which would be observed in isolated molecules. The absorption coefficient in this case has maximum value. On both sides from frequency ν_0 the absorption coefficient first sufficiently sharply, and then increasingly more slowly decreases. Theoretically the wings of lines extend to infinity, but virtually already at a comparatively small distance from ν_0 absorption in wings can be disregarded in comparison with absorption in center.

For the characteristic of the width of the duct/contour of the line of absorption, is introduced the concept of the half-width of line. Usually by the half-width of line, it is accepted to understand the value of width at the level of half from the maximum value of the absorption coefficient.

The width of the lines of the absorption of atmospheric gases in essence depends on the collisions of molecules with each other and on the Doppler effect. The essence of the latter lies in the fact that if the absorbing molecule at the moment of energy absorption moves, then the recorded frequency of absorption differs from falling/incident in dependence on value and direction of speed of motion. Since the molecules of atmospheric gases test chaotic thermal agitation, then the Doppler duct/contour of the line must be symmetrical. Its half-width depends on square root on temperature.

Furthermore, Doppler half-width is proportional to frequency ν_0 and it is inversely proportional to square root of the mass of the absorbing molecule.

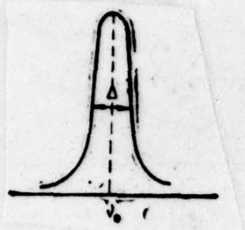

Fig. 8. Duct/contour of the line of absorption.

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For the lines of the absorption of atmospheric gases, Doppler width at temperature of 0°C is included within limits approximately from 0.03 to 0.0003 cm^{-1}. The Doppler half-width of any line of absorption with height/altitude in the troposphere and the stratosphere varies within the limits with ±15o/o. During the solution of many practical tasks, it is accepted to disregard these changes.

The duct/contour of the line of the absorption of atmospheric gases, caused by the collision of molecules, usually is called dispersive. Dispersive half-width is proportional to pressure and it is inversely proportional to square root of temperature. Under the standard conditions (pressure is equal to 1 atm., temperature of 0°C)

the width of line depends on that, between what energy levels of molecule occurred the transition, corresponding to this line. In other words, each line, generally speaking, has its eigenvalue of half-width.

The dispersive half-widths of the lines of the absorption of atmospheric gases in atmospheric boundary layer are measured by values from several hundredths to several tenths of kayser and, as a rule, considerably exceed Doppler half-widths. In proportion to lift, they decrease, they reach Doppler values, and then become all less and less them. The equality of the dispersive and Doppler half-widths for the overwhelming majority of the lines of atmospheric gases is observed in the range of height/altitudes from 10 to 30 km.

The intensity of the wings of Doppler duct/contour decreases in proportion to removal/distance from the center of line noticeably faster than in the case of dispersive duct/contour (Fig. 4).

Thus, with the equality of the half-widths of the lines of Doppler and dispersive duct/contours absorption in their distant wings very strongly differs.

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If at sufficient removing of line from center it is possible to boldly disregard Doppler broadening, then one cannot fail to consider the broadening, caused by the collisions of molecules. Moreover, by precisely last/latter phenomenon is caused the different from 0 radiation absorption of any wavelength of optical range in the atmosphere (including absorption far from lines).

CHARACTERISTIC OF THE SPECTRUM OF ABSORPTION OF WATER VAPOR.

Water vapor - main absorbing gas in the visible, infrared and microwave regions of the spectrum. To it belongs the dominant role in the integral absorption of solar radiation.

The molecule of water vapor (H_2O) is isosceles triangle in apex/vertex of which is located oxide atom. Apex angle is equal to 104°30, and the interatomic distance of hydrogen and oxygen -0.958 Å.

The electron spectrum of water vapor is arrange/located in the distant ultraviolet region (wavelength shorter than 1860 Å), where the atmosphere completely absorbs solar radiation.

The vibrational-rotational spectrum of absorption of water vapor is extremely complex and rich in bands and lines.

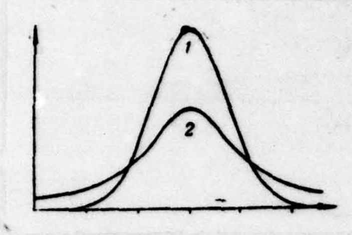

Fig. 4. The form of the duct/contours of lines, caused by expansion because of the Doppler effect (1) and of effect of the collisions when intensities and widths of lines are equal.

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Experimentally detected several ten thousands of lines in the vibrational-rotational bands H_2O, moreover far not all weak lines are taken into account. Complexity and complication of the vibrational-rotational spectrum of water vapor is caused by the fact that the molecule of water belongs to molecules of the type of asymmetric gyroscope. Its principal moments of inertia, being not very large in absolute value, differ from each other in ratio 1: 2: 3. The small moments of inertia and the asymmetry of gyroscope cause the presence in the spectrum of absorption of a large quantity of overlapping absorption bands, literally sown by the tightly arranged/located lines.

Entire vibraticnal-rotaticnal spectrum cf water vapor occupies the visible and infrared region of the spectrum approximately to wavelength of approximately 10 μ. Most interse vibrational-rotational bands are arrange/lccated in infrared region. Their centers have wavelengths 6.3; 3.2; 2.7; 1.87; 1.38; 1.1; 0.94 μ. The intensity of these bands, can be judged from such numerals. At the average values of humidity, entire/all thickness of the atmosphere completely absorbs solar radiation in regions of the spectrum approximately from 5.5 tc 7.5 μ (because of band 6.3 μ) and from 2.6 to 3.3 μ (because cf pouring bands 3.2 and 2.7 μ)/ the intensity of bands decreases in proportion tc approach/approximation to the visible region of the spectrum, which intense bands does not contain. For this very reason the atmosphere appears before us white, although its entire/all visible region contains a sufficiently considerable quantity of weak lines of water vapor.

For the illustration of the character of the spectrum of absorption of water vapor, let us give the experimental recording of the part of the vibraticnal-rotational band 1.38 μ by the width a total of 0.07 of μ, obtained with the aid of the spectroscopic instrumentation of high resolution (Fig. 5). Figure 6 depicts the theoretically designed, completely solved region of the spectrum of

the part of the absorption band 2.7 μ (section 3850-3900 cm^{-1}, or 2.56-2.60 μ).

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The used in calculation precipitated layer of water 0.001 cm corresponds in atmospheric boundary layer in atmospheric humidity 10 g/m^3 to the distance in all 1 m. Thus, 1 m of path it is sufficient so that the emission/radiation in the centers of a series of lines would be completely absorbed.

In the center sections of the absorption bands of water vapor by 6.3 and 2.7 μ it is possible to meet the lines, which completely absorb emission/radiation already on the first millimeters of its path in the atmosphere.

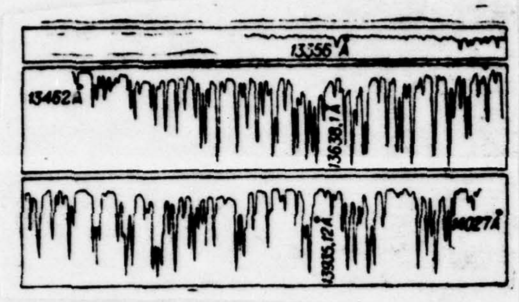

Fig. 5. Spectrum of absorption of the part of the vibrational-rotational band of water vapor of approximately 1.38 km.

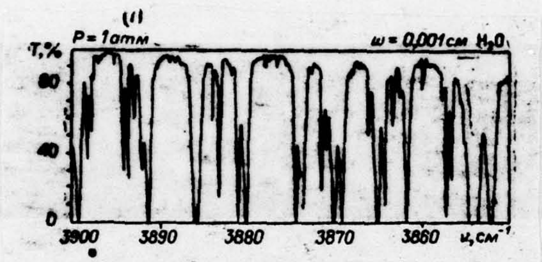

Fig. 6. Dependence of radiation absorption in region of the spectrum 3850-3900 cm^{-1} (2.56-2.60 microns) on wavelength at pressure 1 atm. and precipitated layer of water ω=0.001 cm.

Key: (1). atm.

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On the other hand, in the interval/gaps between powerful absorption

bands, in the so-called atmospheric windows, is encountered a large quantity of weak lines whose center sections do not completely absorb solar radiation. Finally, in the micro-windows of the transparency of the atmosphere, i.e., the narrow regions of the spectrum, completely free from lines, absorption can prove to be the entirely insignificant (several percentages for an entire thickness of the atmosphere).

Thus, if we consecutively examine/scan entire vibraticral-rotational spectrum of absorption of water vapor, then it is possible to reveal/detect a mass of the disorderly arranged/located lines and a large quantity of narrow sections of large transparency. The precision determination of atmospheric windows has important applied value, since only through them the laser emission/radiation capable of being spread without essential absorption. However, far not all interval/gaps between lines possess high transparency. So, the sections between the powerful lines, arrange/located in the center sections of the absorption bands, possess the increased transparency in comparison with the central lines of absorption, nevertheless, they intensely absorb emission/radiation. This is connected with the fact that the close wings of powerful lines, store/adding up, give sufficiently intense continuous absorption.

The purely rotational spectrum of the absorption of water vapor occupies the very wide wavelength range (approximately from 8 μ, where it partially overlaps with vibrational-rotational, and to several centimeters). Line intensity purely the rotational spectrum of absorption H_2O first grow/rises with an increase in the length they are water, then, after achieving maximum, it decreases. In area 8-13 μ, there are no powerful lines. Then in region from 20 μ and to several millimeters absorption is so/such intense, that the direct/straight solar radiation does not reach the surface of the Earth.

Everything said about the vibrational-rotational and purely rotational spectra of the absorption of water vapor is related to the basic isotope of the molecule of water H_2O^{16}.

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In the atmosphere are present also isotopes H_2O^{18}, H_2O^{17} and NDO (heavy water). Their content is respectively equal to 0.2039, 0.0373 and 0.0298o/o, but basic isotope - 99.729o/o.

The spectra of absorption of isotopes H_2O^{18} and H_2O^{17} are very similar to the spectrum of absorption of basic isotope and are somewhat shifted. The spectrum of absorption of NDO noticeably

differs frcm spectrum H_2O^{16}.

For the quantitative estimaticn of the radiation absorption of lasers with different wavelengths in the atmosphere undoubtedly it is necessary to have precise data cn the spectra cf absorption of all isctopes, although their concentrations comprise tenth and one hundredths of a percent, and first cf all - lines of absorption, which fall intc micro-window cf the transparency of the atmosphere.

SPECTRA OF ABSORPTION OF OTHER ATMOSPHERIC GASES.

Carbon dioxide. Its concentration in the atmosphere composes a tctal cf 0.03o/o; however, intense oscillatcrily [rotation bands cause powerful atmospheric absorbtion. Are most intense bands in area 4.3 and 15.0 μ Band 15.0 μ occupies the range cf wavelengths approximately from 12 to 20 μ. In its center section (approximately frcm 13.5 tc 16.5 μ) vertical so/such of the atmosphere completely absorbs solar radiation. Band 4.3 μ occupies area from 4.1 to 4.5 μ. This is the most intense vibrational-rotaticnal band among the bands cf all atmcspheric gases. For it the characteristically sharp decrease of intensity at edges. Solar radiation is absorbed completely in its center secticn approximately from 4.2 to 4.3 μ in the vertical cclumn of the atmosphere above 25 km.

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Furthermore, carbon dioxide has bands with a width approximately 0.1 μ with centers about the wavelengths in descending order of the intensity: 2.7; 4.8; 5.2; 2.0; 10.4; 9.4; 1.6; 1.4 μ and a series of the very weak bands, which do not exert a substantial influence on the wave absorption of optical range. All the vibrational-rotational absorption bands of carbon dioxide are very rich in the lines of absorption. Probability to meet the lines of absorption CO_2 in the atmospheric windows beyond the limits of the bands indicated is considerably less than in water vapor.

The molecule of carbon dioxide has the isotopes: $C^{12}O_2^{16}$; $C^{13}O_2^{16}$; $C^{12}O^{16}O^{17}$; $C^{12}O^{16}O^{18}$, whose content with respect to the common/general/total content of CO_2 in the atmosphere is equal with respect to 98.420; 1.108; 0.0646 and 0.4078c/c. It is logical that all these isotopes have their inherent absorption spectra. The intensity of absorption by the appropriate bands and lines is proportional to the concentration of isotopes. The spectra of all isotopes are somewhat shifted relative to each other.

Carbon dioxide does not have purely rotational spectrum.

Ozone. Its molecule on its structure resembles the molecule of

water vapor: this isosceles triangle with apex angle 116°49' and sides (interatomic distance of oxygen) in 1.278 Å.

The electron spectra of ozone contain the relatively powerful bands, arrange/located in the ultraviolet region of the spectrum (wavelength are shorter than 3400 Å) and sufficiently weak bands in 4500-7400 Å (visible range areas. The ultraviolet absorption bands of ozone strongly attenuate/weaken solar radiation in the atmosphere. Maximum absorption in the vertical column of the atmosphere in visible range does not exceed several percentages. If this absorption was considerable, the atmosphere would be painted.

The vibrational-rotational spectrum of absorption of ozone is arrange/located in infrared region.

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Most intense band is located in area 9.6 μ. Furthermore, ozone has an absorption band with center approximately 14.1 μ and a series of narrow ones, by width approximately 0.1 μ, bands about wavelengths 1.7; 3.27; 3.59; 4.75; 5.75 μ.

The center section of the absorption band 9.6 μ, by width approximately 1.0 μ, in the vertical column of the atmosphere absorbs

to the half of solar radiation in this region of the spectrum. It is very rich in the lines of the absorptions which thus far could not be completely solved in the spectrum during experimental investigations. Other absorption bands either overlap with more powerful bands of water vapor and carbon dioxide, or are not vital importance in the integral absorption of solar radiation in the atmosphere. However, during the estimation of absorption in the separate very narrow, "laser" small sections of the spectrum, can have vital importance the absorption of any, even weak line.

In the atmosphere are present three isotopes of ozone: O_3^{16} basic; $O^{16}O^{18}O^{18}$ and $O^{16}O^{16}O^{18}$, content of which is equal with respect to 99.4; 0.2 and 0.4o/o. The spectra of isotopes are somewhat shifted relative to each other. The role of separate isotopes in the integral absorption of the optical absorption of optical radiation is proportional to their concentration.

Ozone has very intense, purely rotational spectrum of absorption, arrange/located in microwave region.

Oxygen is located in the atmosphere in molecular and atomic states. Atomic oxygen appears as a result of dissociating the molecules O_2 under the action of short-wave ultraviolet solar radiation. It has one weak line of absorption in wavelength 5571 Å

and group of lines of small intensity in region of the spectrum 6300-6364 Å.

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Molecular oxygen possesses very intense electronic absorption bands in the ultraviolet region, which cause the total absorption of short-wave ultraviolet solar radiation in the atmosphere (wavelengths are shorter than 1800 Å). In the near infrared region of the spectrum, is detected the absorption of solar radiation by two electronic absorption bands whose centers are arrange/located about wavelengths 1.2683 and 1.0674 μ. Analogous bands, but shifted into the visible region of the spectrum, in the molecule of the isotope of oxygen $O^{16}O^{18}$. Their centers are arrange/located about wavelengths 0.7620 and 0.6901 μ.

Oxygen has also bands of continuous absorption in the visible and near the infrared regions of the spectrum, obliged by its origin to the complexes of molecules O_2+O_2. However, the intensity of these bands is small, and the account of this absorption necessary only in the special cases (for example, during the propagation of emission/radiation through entire thickness of the atmosphere in the directions, close to the horizon).

Nitrous oxide (N_2O). Its powerful electronic bands are located in distant ultraviolet region. Basic vibrational-rotational absorption bands are arrange/located in areas of wavelengths 17.0; 7.8 and 4.6 μ. First two wholly overlap with powerful bands 15.0 μ CO_2 and 6.3 μ H_2O. Narrow band 4.6 μ distinctly is exhibited in the spectrum of absorption of solar radiation in the earth's atmosphere. Besides normal bands, molecule N_2O has many bands of weak intensity, which do not have any essential effect on the integral absorption of solar radiation in the atmosphere.

The molecule of nitrous oxide has 12 stable isotopes, formed by the combination of atoms N^{14}, N^{15}, O^{16}, O^{17} and O^{18}. The spectra of absorption of isotopes are studied weakly. We can happen, which during the study of the propagation of highlymono-chromatic emission/radiation it is necessary to consider the absorption of a series of the relatively weak lines, which fall into the narrow atmospheric windows.

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Methane (CH_4). The electronic bands of its absorption are arrange/located in the distant ultraviolet region of the spectrum (wavelength are shorter than 1450 Å). Basic vibrational-rotational absorption bands have centers about wavelengths 7.7 and 3.3 μ. The

first wholly overlaps with the powerful band 6.3 μ of water vapor. Is sufficiently narrow, by width approximately 0.1 μ, band 3.3 μ distinctly is exhibited in the spectrum of absorption of solar radiation in the atmosphere. One of the lines of the absorption of this band, as it seemed, coincides with the line of the emission/radiation of gas laser on the mixture of helium with neon (wavelength 3.39 μ), which in practice makes with impossible the use of this laser on long routes in the atmosphere.

Methane has sufficiently many other vibrational-rotational absorption bands; however, in the earth's atmosphere they are not exhibited or are exhibited weakly even with the longest inclined paths of the propagation of radiation.

Purely rotational spectrum methane does not have.

Carbon monoxide (CO) in the which interests us area of the scale of the electromagnetic waves has the basic vibrational-rotational band with a width of 0.1 μ with center approximately 4.67 μ. This band more or less distinctly is exhibited in the spectrum of absorption of solar radiation in the earth's atmosphere. Other vibrational-rotational absorption bands CO overlap with more powerful bands of water vapor and carbon dioxide or have too small an intensity.

The purely rotational spectrum of the absorption of carbon monoxide is arrange/located in distant infrared and microwave regions and completely overlaps purely with the rotational spectrum of water vapor.

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ATMOSPHERIC WINDOWS.

The absorption of optical radiation in the atmosphere occurs simultaneously almost by all atmospheric gases. Therefore the important for practice atmospheric windows can be determined, studying the absorption of the earth's atmosphere under natural conditions. Is most simple and convenient the method of measuring the transparency of an entire thickness of the atmosphere or of its separate layers during the use of this powerful/thick and wide-range radiation source as the Sun. It is well known, for example, that the radiation spectrum of the Sun covers the wide wavelength range, into which, in particular, enter the ultraviolet, visible, infrared and microwave regions of scale of the electromagnetic waves.

Figure 7 gives the spectrum of solar radiation in the range of wavelengths from 0.1 to 100 μ on the surface of the Earth (upper curve), also, at the height/altitude of 11 km (lower).

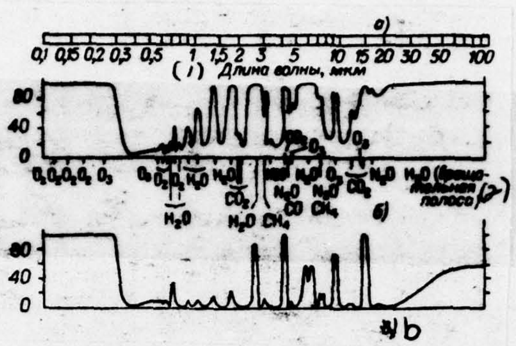

Fig. 7. Common picture of the spectrum of absorption of the solar radiation cf the earth's atmosphere in the range of wavelengths from 0.1 to 100 μ (at ground level - upper curve, at the height/altitude cf 11 km - lcwer curve).

Key: (1). Wavelength, μm. (2). Rotation band.

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Both curves are obtained under the most probable conditions in the pure/clean atmosphere (aerosol scattering can be disregarded) at the solar altitude of 40°. Curves are obtained smoothed the fine structure of the spectrum of absorption of each band, but distinctly are isclated very absorption bands.

Figure shows positions, width and intensity of the normal bands of the absorption of all atmospheric gases, about which the speech

occurred in the preceding/previous paragraphs. As is evident, entire/all thickness of the atmosphere completely absorbs solar radiation in wavelengths shorter than 0.3 μ and longer than 20 μ. The absorption of ultraviolet region is caused by ozone and oxygen, but in distant infrared region - by water vapor. Completely it is clear that the regions of the spectrum indicated cannot be used either for communication/connection or for the transmission of information nor for solving other practical problems, if the corresponding equipment works in atmospheric boundary layer.

The wavelength range from 0.3 to 20 μ consists of the alternating atmospheric windows and absorption bands. Is most transparent in this range entire/all visible and nearest infrared region of the spectrum. Widest atmospheric windows in infrared region - window with centers approximately 3.6 and 10 μ. The latter in the literature is accepted to call the long-wave atmospheric window. In the middle of this window, which occupies region of the spectrum from 8 to 13 μ, is arrange/located the most intense absorption band of ozone with center approximately 9.65 μ.

Each of the presented in Fig. 7 absorption bands consists of of hundred and thousands sufficiently tightly arranged/located lines. Although the absorption between lines is considerably less than the absorption in the centers of lines, nevertheless in an entire

thickness of the atmosphere is achieved total absorption for any wavelength in the center section of the band.

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The difference in the absorption coefficients in the centers of lines and between them is exhibited in the fact that if for total absorption in the interval/gaps between lines to solar radiation it is necessary to traverse entire thickness of the atmosphere, then in the centers of lines complete absorption is reached at different height/altitudes far from the surface of the Earth depending on line intensity.

Thus, if monochromatic laser emission/radiation falls into the center section of any absorption band, it is possible previously to say from the lack of promise of the practical application/use of this laser in the equipment/devices, intended for the work through the atmosphere, although the absorption coefficients for different wavelengths in different bands can differ in ten, hundred or more times. It is important that the lowest values of coefficients in the centers of the powerful bands of sufficient ones for, emission/radiation completely would be absorbing in atmospheric boundary layer during distribution to distance several kilometers.

Consequently, if one or another laser is develop/processed for systems, that work through the atmospheric boundary layer, the wavelength of its emission/radiation must fall into one of the atmospheric windows. But if discussion deals with the use of optical radiation at different height/altitudes upward, then the possibilities of the practical use of different wave bands grow/rise the greater, than higher operating altitude. Figure 7 shows that at the height which exceeds 11 km, substantially grow/rises the transparency in area of the majority of the absorption bands of atmospheric gases, in particular in the absorption bands of water vapor. In fact, in the layers of the atmosphere, arrange/located it is above 11 km, remains powerful absorption in three absorption bands of carbon dioxide with centers in 15.0; 4.3 and 2.7 μm, also, in the band of ozone 9.65 μm.

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Completely it is clear that the most transparent sections of wavelengths for monochromatic radiation are located in the atmospheric windows. However, it cannot be previously said, to what extent is promising for use in the atmosphere one or the other wavelength of laser emission only on the basis of the fact that it falls into atmospheric window. The fact is that all atmospheric windows have the weak lines of the absorptions which can not play any

of vital importance in the integral absorption of continuous solar radiation in the atmosphere. Precisely therefore during the experimental recording of the spectrum of absorption of solar radiation in the earth's atmosphere with rough spectral resolution in atmospheric windows absorption is not virtually detected. However, these weak lines of absorption can become serious barrier/obstacle, if laser emission/radiation falls into their center section. Therefore is very important the high resolution of the spectra of absorption of atmospheric gases in the atmospheric windows and the determination of the position of the centers of all lines with the accuracy, unattainable for the existed previously methods. Is not less is necessary so precision determination of the position of the lines of laser emission.

ABSORPTION OF LASER EMISSION IN THE ATMOSPHERE.

Many accumulated for years of materials research about the absorption of optical radiation in the atmosphere cannot be used during the quantitative estimation of the absorption of laser emission/radiation in the atmosphere, because with the applied methods of study it was not possible to determine with the necessary accuracy the position of the centers of lines and absorption coefficients. Weak narrow lines were frequently not at all recorded by equipment.

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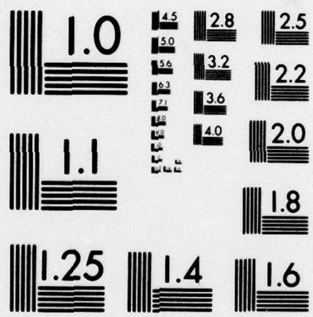

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By the author it is establish/installed, that if the line of laser emission/radiation falls into the center section of the line of absorption, then in atmospheric boundary layer centers of both of lines must be determined with an accuracy tc 0.01-0.02 cm^{-1} for the wide lines of absorption and with accuracy larger than 0.01 cm^{-1} - for narrow cnes. With height/altitude these requirements become ever more and more rigid, since with an increase in the height/altitude sharply decreases the width of the lines of absorption.

The coefficients of absorption of the lines of atmospheric gases in the center sections of the lines very sharply change with frequency. In atmospheric boundary layer in the widest lines of the absorption of water vapor, the absorpticn ccefficient decreases by 10o/o, if we go away from the center of the line in all on 0.03 cm^{-1}. In the case of narrow lines for achievement of the same effect, it suffices to be shifted from the center of line cn 0.01 cm^{-1}. But at the height/altitude of 15 km displacement from the center of the line cf absorption on 0.01 cm^{-1} leads to a change in the absorption coefficient already to 10-15o/c in dependence cn the width of line. Thus, caused by one or the other reasons insignificant, to the

hundredth of kayser, the shift/shear of the line of laser emission, if line itself is located in the center section of the line of absorption, can lead to a powerful change in the transparency of the atmosphere. This is connected with the fact that the transparency of the atmosphere changes not proportional to a change in the absorption coefficient, but the more powerful, the more path it passes emission/radiation in the atmosphere (transparency is described by the exponential function as index of which serves the product of the absorption coefficient up to distance).

In chapter about the properties of laser emission/radiation, we speke about the possibility of the directed change in its wavelength during the use of magnetic and electric fields to the value, equal to to approximately one kayser.

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If this rearrangement of the length of wave of emission/radiation occurs in area of the center section of the line of absorption, then it is completely sufficient in order to leave from the region of the high transparency of the atmosphere into the region of powerful absorption, and vice versa. Realized by other methods rearrangement of the wavelength of laser emission in considerably more broad band leads to repeated (according to a number of lines of absorption in

the reconstructed range) transition from the regions of powerful absorption in the region of high transparency (micro-window of transparency).

In practice, together with the directed change in the wavelength of laser emission, we encounter, also, with the cases when as a result of uncontrollable changes in generation conditions the wavelength of emission/radiation can be charged so that the atmosphere first sufficiently freely passes emission/radiation, then becomes difficultly surmountable barrier on its path. Typical example - emission/radiation of the most widespread in practice laser on ruby.

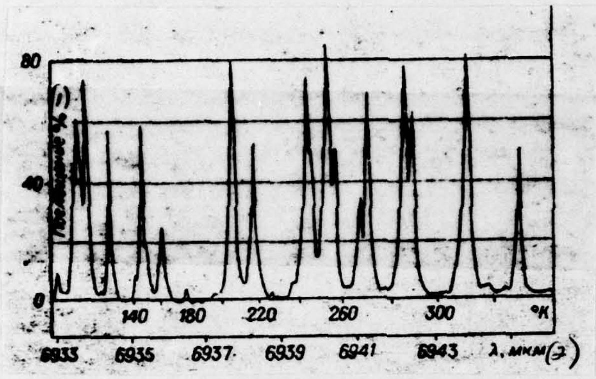

Fig. 8. Recording of the fine structure of the spectrum of absorption of the earth's atmosphere in area of laser emission on ruby.

Key: (1). Absorption. (2). μm.

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In Fig. 8 along the vertical axis is plotted the dependence of the radiation absorption of solar radiation by an entire thickness of the earth's atmosphere on wavelength, measured by the instrument of high spectral resolution in the range of wavelengths from 6933 to 6944.5 Å. Along horizontal axis are in parallel with wavelengths shown the temperatures of ruby by which the laser emits the appropriate wavelengths. As can be seen from figure, the absorption of an entire thickness of the atmosphere is virtually changed from zero in the interval/gaps between lines to 60-80o/o in the centers of the

majority of lines. One should in this case emphasize that in area of laser emission on ruby there are no powerful lines of absorption. In addition, very spectrum of absorption of the atmosphere it is written with the instrument although of high resolution, nevertheless insufficient for obtaining of the completely undistorted absorption spectrum. In reality the peaks of absorption must be even acute/sharper and higher.

Consequently, the quantitative estimation of the absorption of laser emission/radiation in the atmosphere is the very fine/thin, complex and difficult problem, for satisfactory solution of which it is necessary to create the new methods both of experimental and theoretical studies.

Such methods are develop/processed by the author with the colleagues of our institute.

Method of laser source.

The direct experimental determination of the coefficients of absorption of atmospheric gases in areas of laser emissions of contemporary equipment cannot ensure the required accuracy.

If we as radiation sources utilize lasers themselves, then

directly frcm experiment it is possible to obtain quantitative absorption characteristics cf their emission/radiation. The essence of the method of measurements in this case is reduced to following. Laser emission is form/shaped with the aid cf the system of optical cbjectives into more narrow beam (so-called collimated) and is headed fcr atmosphere.

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At the specific distance from laser, is placed the receiver, which consists of mirror, completely intercepting beam, and unit of equipment for measuring assembled of the focus of mirror laser energy. The part of the energy of laser emissicn/radiation at output frcm scurce is abstract/removed with the aid of calibrated semitransparent plate intc monitoring channel for measuring of initial power and wavelength of emissicn/radiation.

This method makes it pcssible to establish/install the absolute weakening cf laser emission/radiation in the atmosphere under one or the other conditions which are monitored by the appropriate equipment during measurements. Distance from source tc receiving system cannot be arbitrary. Its maximum value is determined by the diameter of receiving mirror and the angle cf the divergence of source. If one ccnsiders that with divergence in one second of arc the diameter of

beam increases by 0.5 cm on path 1 km, then not difficult to calculate which with the diameter of receiving mirror 1 m for a complete interception beam at a distance of 10 km is necessary that the angle of divergence would not exceed 20 seconds of arc, which is is completely attainable. However, large distances during measurements are necessary only when the weakening of emission/radiation is small, i.e. with the high transparency of the atmosphere.

Measurements in real atmosphere employing the described procedure give the possibility to obtain the absolute quantitative data on weakening or fading of laser emission/radiation as a result of absorption by atmospheric gases and scattering on the particles of aerosols. These components of weakening can be divided, if parallelly is measured the transparency of the atmosphere with the thermal source, from which with the aid of interference filter is isolated the region of the spectrum in wide approximately 100 Å including the wavelength of laser source.

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In the latter case we are virtually measured only aerosol scattering, since absorption in narrow lines can be disregarded. If narrow laser line falls into area the line of the absorption of the atmosphere,

then during measurement with laser source we is reveal/detected larger weakening than with thermal. The coincidence of the cceffiicients of weakening for laser and thermal sources means that the laser emission/radiation is barely absorbed by atmospheric gases.

The described method was used during the measurements of the transparency of the atmosphere for the emissicn/radiations of the most widely used lasers: gas - on the mixtures of helium with neon (wavelength of emission/radiation 0.63; 1.15 and 3.39 μ), helium with xencn (wavelength 3.51 μm), carbon dioxide with nitrogen (wavelength 9.3 and 10.6 μm), on the vapors of cadmium (wavelength 0.44 μ), sclid-body - on ruby (wavelength 0.69 μm), cn glass with neodymium (wavelength 1.06 μm), on flcorite with dysprosium (wavelength 2.36 μm) and semiconductor laser on gallium arsenide (wavelength 0.84 μm).

Measurements showed that the laser emissicns with wavelengths of 0.44; 0.63; 0.84; 1.06; 2.36 and 3.51 μm are barely absorbed by atmospheric gases. Emission/radiation it is laser on ruby, as one would expect, it depended substantially on the temperature of the ruby (absorption coefficient changed more than 5 times).

The line of the emission/radiation of gas laser in wavelength 1.15 μm falls into wing of one of the lines of the absorption of water vapor. The absorpticn coefficient proved to be equal to 0.3

mm^{-1} of the precipitated layer of water. Table 2 gives designed with the use of this coefficient of the value of the transparency of the atmosphere for distances 0.1; 0.5 and 1.0 km in atmospheric boundary layer with different absolute humidity.

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Absolute humidity from 1 to 15 g/m^3 most frequently is encountered in the atmosphere (it corresponds to saturation pressure at temperatures from -2 to +18°C). Table 2 demonstrates the rapid decrease of the transparency of the atmosphere with distance with high humidity because of respectively larger index in the exponential function, which describes a change of the transparency in dependence on the distance of the propagation of emission/radiation. On the other hand, from table it is evident that laser in wavelength 1.15 μ whose emission/radiation falls not to the center of line, and somewhere into the middle of wing, cannot be considered as promising for practical application/uses in the atmosphere.

The emission/radiation of gas laser in wavelength 3.39 μ on pure/clean chance falls directly to center sufficient to the weak line of the absorption of methane. On the integral absorption of continuous emission in this area, this line does not have any noticeable effect, but for laser emission/radiation it is

considerable barrier. In atmospheric boundary layer, the absorption coefficient render/showed to equal several reverse/inverse kilometers. With this coefficient at a distance in several kilometers are absorbed more than 99o/o emission/radiation. Thus, the weak line of methane became serious obstruction for using the laser.

Table 2. Transparency of atmospheric boundary layer for laser emission in wavelength 1.15 μ, o/o.

Дистанция, км (1)	Абсолютная влажность, г/м³ (2)			
	1	5	10	15
0,1	97	86	74	64
0,5	86	47	32	11
1,0	74	22	5	1

Key: (1). Distance, km. (2). Absolute humidity, g/m³.

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The described method in the modified form was utilized under laboratory conditions for measuring the pure/clean radiation absorption of lasers in wavelengths 1.15 and 3.39 μ. Modification consisted in the fact that the laser emission was headed for the vacuum multipass cell, which was being filled by the mixture of atmospheric gases. The optical system of cell allowed via multiple reflection from mirrors to create the path of laser beam, equal to 96 m in the synthesized atmosphere, with the distance between mirrors 2 m.

In conclusion let us note the limitedness of the method of laser source. The obtained with its aid absolute values of the transparency of the atmosphere can be used for the quantitative estimation of

radiation absorption in atmosphere only of those types of the lasers, with which were conducted the measurements.

Method of laser spectroscopy.

By the universal method, which ensures the necessary quantity of data on the absorption of laser emission/radiation with any wavelength, it is possible to recognize only such, which makes it possible to obtain the undistorted, completely allowed spectrum of the absorption of any of atmospheric gases and their mixture under laboratory or natural conditions. Only it is capable to give the reliable information about the radiation absorption of laser with any spectrum. Only this method will make it possible finally to find all micro-windows of the transparency of the atmosphere and to obtain the quantitative data on the absorption coefficient in them. The development of this method is extremely important for many applied problems of meteorology, astrophysics, astronomy, different forms of the technology, which uses emission/radiation of the optical wavelength range.

None of the applied to recent years methods of the experimental study of the absorption spectra gave to specialists the virtually completely solved and undistorted spectra.

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In recent years of beginnings intensely to be developed the method of a Fourier-spectrometry. The spectra of high resolution in it are obtained not directly in experiment, as usual, but after corresponding processing of the results of measurements, with the use of high-precision and complex interferometers. The record/written signal contains information about the coefficients of absorption of the whole series of close wavelengths. Interpretation of signal and obtaining spectra produce with the aid of electronic computers. But thus far is created the only unique instrument, which makes it possible to determine the position of the centers of the lines of absorption with an accuracy to several thousanths of kayser. Therefore it is difficult now to say, be managed to develop the method of a Fourier-spectrometry to such an extent that it would become universal, universal.

The high monochromaticity of laser emission/radiation in connection with the possibility to change the length of its wave open/discloses the tempting prospect for the creation of the completely new method of spectroscopy of superhigh resolution - laser spectrometry. Its essence consists of following. If we through the absorbing medium pass monochromatic radiation, then, after measuring its intensity upon the entrance into medium and on leaving and path

length in medium, it is possible to calculate the monochromatic absorption coefficient. Emission/radiation must have such spectral width within limits of which the absorption coefficient can be considered being independent of wavelength.

It is known that the absorption coefficient decreases double during removal/distance from the center of line by the hundredth or tenths of kayser. Consequently, for measuring the absorption coefficient in the center sections of the lines the width of emission/radiation must be at least several times of less than the half-width of the lines of absorption.

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Calculations show that at a pressure of approximately 1 atm. the spectral width of the emission/radiation, utilized for the measurements of the absorption coefficient in the central sections of lines, must be not more than 0.01 cm^{-1}. If measurements are conducted at a lower pressure, then, is logical, must decrease the width of emission/radiation.

At present, on one hand, in gas and even solid-body lasers the degree of the monochromaticity of emission/radiation may be reduced to 10^{-3} cm^{-1}, on the other hand - are developed, the methods of the

controlled change of the wavelength of laser emissions over a wide range of wavelengths. If it would be possible to combine in one laser high monochromaticity and controllability of emission/radiation, then the problem of laser spectroscopy would be solved. But demonstration is this matter of the future.

The prospect of obtaining the undistorted duct/contour at least of one lines of absorption is so tempting which would be unwise to await, when laser technology achieves such level, that in one and the same generators high(ly)-chromatic emission/radiation can be it will be obtained during a continuous change of the wavelength over a wide range of values. In the institute of optics of the atmosphere, are developed two laser spectrometers. In their creation participated the author of the book. The first spectrometer makes it possible to obtain the undistorted duct/contour of one lines of absorption, second - the undistorted completely solved region of the spectrum, which contains several lines of absorption.

As the basis of the first laser spectrometer, lay the use of a change in the wavelength of the emission/radiation of gas laser under the influence on it of magnetic field. Is achieved this by the location of laser into the solenoid, with the transmission of the current through which appears the magnetic field. The the heavy current in the turns of solenoid, the the large magnetic intensity it

is created and the sharper is shift/sheared the wavelength of laser emission/radiation. In the mock-up of our instrument, maximum current was equal to 10 A.

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To it corresponded maximum magnetic intensity 625 Oe, which caused the shift/shear of the line of the emission/radiation of gas laser on $\pm 0.02\ cm^{-1}$. Was utilized laser on the mixture of helium with neon in wavelength 3.39 μ. The wavelength of the emission/radiation of this laser is close to the center of the line of the absorption of methane from band 3.3 μ. Smoothly changing magnetic intensity, we just as smoothly change the wavelength of laser emission, gradually taking away it from the center section of the line of absorption to periphery. The wavelength of laser emission increases or decreases in dependence on direction of flow in solenoid and of corresponding to it sense of the vector of strength of magnetic field. The shift/shear of the wavelength of emission/radiation on $\pm 0.02\ cm^{-1}$ proved to be sufficient in order to obtain the duct/contour of the line of the absorption of methane.

In the first version of instrument, was utilized multimode laser in the new, improved version - stabilized one-mode. Figure 9 depicts the duct/contours of the lines of the absorption of methane, obtained

during the use of cne-mode and multimode lasers at a pressure in several thousanths of the atmosphere.

In figure distinctly visible the difference in duct/contours, which attests to the fact that the usual multimode gas lasers cannot give the undistorted duct/contour of the line of the absorption: the half-width of the line of methane under conditions of the atmosphere is equal to several hundredths of kayser, but the width of the line of the emission/radiation of multimode laser 0.01 cm^{-1}. Let us note that the line of the emission/radiation of one-mode laser in wavelength 3.39 μ taking into account a change in the position of its center occupies region of the spectrum not more than 0.001 cm^{-1}, i.e., it it is substantially less than halfwidth of the investigated line of absorption.

Instrument makes it possible to obtain the undistorted duct/contour of the line of absorption and with its aid to investigate the effect of the varied conditions of medium (pressure, impurity/admixtures, temperatures) for abscrption of emissicn/radiation in individual line.

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This investigation they will aid faster to penetrate in the mysteries

cf the mechanism of luminous absorption by substance.

True, a deficiency/lack in the instrument lies in the fact that with its aid is possible to thoroughly investigate only one line of absorption.

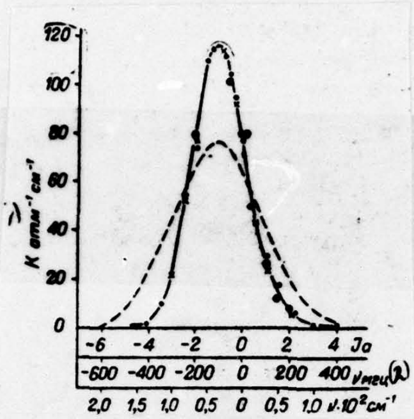

Fig. 9. Duct/contours of the lines of the absorptions, obtained with the aid of laser spectrometer on the basis of one-mode and multimode gas lasers at wavelength 3.39 μm. Along the horizontal axis are plotted the values of current strength in solenoid in amperes and the corresponding to them changes of the emission frequency of laser in MHz and kaysers. On vertical axis are plotted/applied the values of the coefficient of absorption of methane in unity the atmosphere to centimeter into minus of the first degree (sense of this unity it consists in following: for determining the absorption of this layer of gas, is necessary its pressure, expressed in the atmosphere, to multiply by thickness of the layer in centimeters, then total it is necessary to multiply by the absorption coefficient in $atm^{-1} \cdot cm^{-1}$; the obtained value exists an optical thickness of layer, or index in the exponential law of radiation damping.

Key: (1). $atm^{-1} \cdot cm^{-1}$. (2). MHz.

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In the second mock-up of the created by us laser spectrometer, is utilized the laser emission on ruby in the conditions/mode of free generation. The momentum/impulse/pulse of this emission/radiation consists of consecutively following one after another of spikes (spectrally narrow lines of emission/radiation) with different wavelengths. The spectral width of each beam is approximately equal to 0.01 cm^{-1}. In momentum/impulse/pulse with spectral width in several tenths of kayser are contained several ten spikes, more than or less evenly covering the emitted interval of wavelengths. Thus, if we could record the intensity of each spike upon the entrance into the absorbing medium and on leaving from it and with high accuracy measure the wavelength of each spike, we would obtain the possibility for one emission impulse to measure immediately several ten values of the absorption coefficient. It is clear that for this is necessary the high-precision high-speed equipment, since the pulse duration is measured by microseconds.

In our instrument simultaneously are utilized the electro-optical scanning (change) of the wavelength of emission/radiation in the process of generation

momentum/impulse/pulse and the hypersonic scanning/sweep of momentum/impulse/pulse with recording of the wavelength and intensity of each spike. For one momentum/impulse/pulse it is possible to obtain the data on the absorption coefficients for several ten wavelengths in the interval of several tenths of kayser. Displacing the emitted by one momentum/impulse/pulse spectrum as whole, during heating or cooling the crystal of ruby, it is possible to bring the interval being investigated to several kaysers. In our experiments was overlapped the interval by width several kaysers. Figure 10 is given the virtually undistorted, completely allowed spectrum of the atmosphere in area of laser emission on ruby, obtained with the aid of our method.

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Figure depicts region of the spectrum by the width a total of 1 of cm^{-1}. According to literature data, in this section must be of 2 lines of absorption however we reveal/detected 10. True, 8 of them very small intensity, but, nevertheless, they were well visible. Discovery/opening these lines, on one hand, convincingly demonstrates the remarkable possibilities of laser spectrometry, with another, it testifies that in the near future we is determined a large number of the not discovered previously weak lines. It is completely possible that all atmospheric windows are densely filled by such lines.

The component part of the described spectrometer one should consider vacuum multipass cell with the basis between rotary mirrors 5 m. Ideal optical and mechanisms of cell together with the system of the preparation of gas mixture, change and of the measurement of their temperature, pressure gases being investigated provide the possibility of the simulation of the conditions in which laser emission/radiation can render/show in atmospheric boundary layer, at different height/altitudes and in different climatic zones.

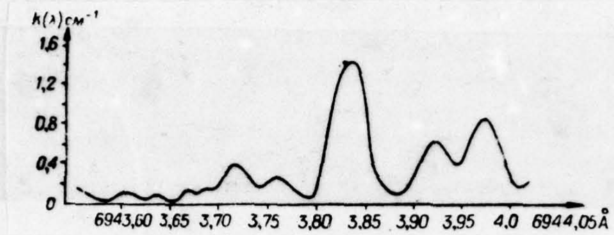

Fig. 10. Spectrum of absorption of the atmosphere, written with the aid of laser spectrometer in area of the emission/radiation of generator on ruby. Along the horizontal axis are plotted the wavelengths, on vertical - an absorption coefficient in the kaysers of the layer of the precipitated water.

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With the distance between rotary mirrors 5 m under laboratory conditions, it is possible to bring because of multiple reflection the path length of ray/beam in cell to 1 km. Pressure in cell can be changed from the decamillion portions of the atmosphere to 2 atm., temperature - from 20 to 90°C.

Theory of absorption.

In principle the problem of the quantitative estimation of the coefficients of absorption of monochromatic radiation or obtaining of the completely allowed spectra of the absorption of atmospheric gases

can solve the theory. However, from possibilities in principle to their practical realization, frequently there is enormous distance. So and here. In fact, for determining the coefficients of absorption of any wavelength it is necessary to have sufficiently precise data in all on three parameters - on the position of centers, intensity, the form of the duct/contours of the lines which can affect radiation absorption from this by wavelength. Theoretically we can determine these parameters, but how accurately?

For obtaining of the absorption coefficients, suitable for the quantitative estimation of the absorption of laser emission/radiation in the atmosphere, it is necessary to have data on the centers of lines with accuracy not less than 0.01 cm^{-1}. In addition, the selected duct/contour of the line must accurately describe real picture, in what we cannot be confident until we obtain the experimental confirmation (practice will always carry final sentence to theory), and finally for calculation are necessary the high-precision data on line intensity. Employing the existed until recently procedures it was not possible to sufficiently accurately determine the initial ones of the parameters and, therefore, to obtain correct final results. They at best gave more or less satisfactory results for the most intense lines, arrange/located in the central areas of absorption bands which were enclosed for practical use.

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Greatest practical interest is of the quantitative estimation of the absorption coefficients in areas of the windows of transparency of the atmosphere with the weak lines of absorption. The calculation of the parameters of weak lines is most difficult. Weak lines, as a rule they appear during transitions between high molecular energy levels which most of all are subjected to the effect of the various kinds of interactions within molecules and between them. It is possible, perhaps, to formulate such qualitative it guided: the weaker the line, the more difficultly it is to determine its parameters. By the way, this rule is applicable also, to the experimental determination of the parameters of lines. At the same time the weaker the line, the there is more the practical interest in its study.

Understanding the enormous practical value of sufficiently precise data on the parameters of the lines of the absorption of atmospheric gases in optical wave band and giving up report on extremely great difficulties, we (author it bears in mind first of all of its colleague-theorists) nevertheless they risked to attempt to create this method of calculation which would make it possible to

obtain the parameters of lines with previously unattainable accuracy.

The many-year stressed work is found in the concluding phase. The created algorithms of the calculation of the parameters of lines allow (this was already made repeatedly) to restore/reduce entire spectrum of vibrational-rotational absorption band, if were known the sufficiently precise parameters of several lines. But the parameters of these several lines thus far cannot be determined theoretically. They need to be obtained experimentally and utilized as the parameters of standardization, or the parameters of scale.

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The solution of complex problem is sufficient precise experimental determination of the parameters of several lines in each absorption band, obviously, it will be connected with the development of the new methods of spectroscopy of superhigh resolution, including methods of laser spectrometry.

Practical use of absorption of laser emission/radiation in the atmosphere.

Until now, we spoke about the absorption of laser emission/radiation in the atmosphere as about interference or barrier

which the atmosphere creates on the path of laser beam. However, in a series of cases this phenomenon can be utilized for solving the important applied problems.

So, gas laser on the mixture of helium with neon, the wavelength of emission/radiation of which coincides with the center of the weak line of the absorption of methane, can be used for measuring methane concentration in the atmosphere with high accuracy.

The absorption of gas laser on the mixture of helium with neon in wavelength of emission/radiation 1.15 μm by water vapor makes it possible to utilize this laser for the precise measurement of humidity, which is especially important in winter, when the existing standard methods do not provide any satisfactory accuracy.

The creation of lasers from the reconstructed by wavelength of emission/radiation will make it possible to utilize generators for precise quantitative determinations of the concentration of any of atmospheric gases. If we for the analytical target/purposes of selecting the powerful lines of absorption, then laser gas analyzers can be it will be made by compact ones.

The second important direction of the use of radiation absorption of lasers in the atmosphere is connected with the laser

sounding of the atmosphere. It proves to be that if we in the atmosphere direct two laser pulses, in one of which the wavelength of emission/radiation coincides with the center of the line of the absorption of atmospheric gas, and in another falls between lines, then of that reflected by the atmospheric aerosol layers of radar echos it is possible to extract information about the airfoil/profile of the concentration of the corresponding atmospheric gas.

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The restoration/reduction of the airfoil/profile of the concentration of one or the other gas indicates the presence of the data on a continuous change in the concentration in the course of the controlled laser beam. Information is obtained virtually instantly, also, without any effect for the objective of investigations.

There is no doubt that both of directions of the use of a phenomenon of the absorption of laser emission/radiation in the atmosphere in the near future will have extensive application during the development of the new methods of the study of the earth's atmosphere whose results are important for many directions of science and technology.

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Chapter Three.

DISSIPATION OF ENERGY OF BEAM IN THE ATMOSPHERE.

Nature of the phenomenon of scattering.

Simultaneously with the absorption of laser emission/radiation the atmosphere is capable it of scattering. The energy losses of ray/beam can occur as a result of the scattering: 1) during the fluctuations (fluctuation - deviation from average value) of the density of molecules (the so-called molecular, or Rayleigh scattering); 2) on the particles of aerosols even 3) on the random heterogeneities of the atmosphere, caused by turbulent air motion.

The physical cause for the dissipation of energy of laser beam in all cases is identical and consists in following. If on the path of light ray is encountered optical heterogeneity, or, speaking in other words, the localized volume the refractive index of which

differs from the refractive index of medium, then beam direction changes. The degree of deviation of ray/beam depends on the difference between the refractive indices of the heterogeneity of medium and on the angle at which the ray/beam enters heterogeneity.

Participating in chaotic thermal agitation, the molecules of air create the random fluctuations of atmospheric density, which are the optical heterogeneities of medium.

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Turbulent air motion, caused, for example, by the wind, also create the heterogeneities in the atmosphere whose size/dimensions are considerably be greater than in the case of the fluctuations of density, caused by the chaotic thermal agitation of molecules. Finally, any particle of aerosols is the clearly expressed optical heterogeneity the refractive index of which noticeably differs from the refractive index of air.

Any deflection of any beam from beam of light leads to the dissipation of energy. The quantitative evaluation of energy losses during scattering is determined by coefficient of scattering. The intensity of diffuse radiation (as absorbed) is described by exponential law. In the index of the exponential, enters the product

cf coefficient of scattering to the path length of ray/beam, passable in the atmosphere.

The calculations of the coefficients of mclecular, aerosol and turbulent dissipation showed that during turbulent dissipation from light beam is derive/concluded incomparably less energy than with molecular and aerosol, and these losses can be disregarded. The random heterogeneities of the turbulent atmosphere, without having noticeable effect on power engineering of laser emission/radiation as a whole, essentially change structure in the cross section of ray/beam.

The molecular scattering of the electromagnetic waves of optical range is is sufficiently well studied. Are comprised the vast tables of coefficients of scattering in the ultraviolet, visible and infrared regions of the spectrum. These coefficients do not virtually depend on time and place, at least in the lower 30-kilometer layer of the atmosphere. On the contrary, coefficients of aerosol scattering substantially affect the size/dimensions, the chemical composition and the concentrations of particles of the aerosols. Each of these parameters is subjected to large variability in time and space.

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Atmospheric aerosols.

The quantitative evaluation of the energy losses of laser emission/radiation because of scattering by aerosols is possible in the presence of the reliable data on all fundamental characteristics of atmospheric aerosols.

Despite the fact that the parameters of atmospheric aerosols are changed within very wide limits, it is possible to isolate some characteristic types: cloud, mist/fogs, mists, dust, fumes, condensation nuclei. To aerosols can be attributed residue/settlings, since in comparison with the velocity of propagation of luminous radiation the rate of the precipitation of residue/settlings is negligible and the particles of residue/settlings can be considered suspended in the atmosphere.

Clouds and mist/fogs are liquid-drop and crystal. The first consist of the spherical particles which can remain liquid and at minus temperatures (the so-called supercooled clouds). Ice clouds and mist/fogs include the particles of irregular form - crystalline particles of ice. Can be encountered also the clouds, which consist of the ice spheres (during the continuous cooling of the supercooled clouds of its particle they freeze).

As the important characteristic of any cloud serves the spectrum of the size/dimensions of its particles, i.e., particle-size distribution. The processes of formation of clouds and fogs are connected with the changing over wide limits different factors, which are determining an increase in the drops and crystals. To them they are related: the dependence of the rate of growth on concentration, on according to sizes, on the nature of condensation nuclei, on temperature and rate of cooling of air, on the scales of turbulence and its intensity, on the sources of moisture, etc. Due to the diversity of these factors thus far it is not possible to solve a question concerning distribution and change in the particles of the clouds and mist/fogs.

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The spectra of the size/dimensions of these particles in different stages of their development are obtained during experimental investigations. In the majority of the cases, particle distribution of the clouds and mist/fogs is described by one-vertex bell-shaped asymmetric curve, typical form of which is shown on Fig. 11.

Clouds and mist/fogs of various forms and stages of development differ from each other in terms of the values of parameters r and Δ. As a rule, at the initial stage of formation of cloud or fog the most

probable radius of particles and a half-width of distribution have minimum value. In other words, condensation only begins, the particle of even smaller size/dimensions, increase they more or less evenly. In different stages of cloud and the mist/fogs can have the different values of parameters r and Δ in dependence on the conditions, under which occur condensation processes. For the clouds, which do not give residue/settlings, most frequently value r is included in the interval of 4-6 μ, but value Δ has sufficiently high value (wide distributions). In the mist/fogs which are formed above airfields with the intense motion of aircraft, value r is usually equal to approximately 1 μ, and value Δ is small (narrow distributions). This is connected with the fact that the exhaust of aircraft contain the nuclear mass of the condensation of approximately identical size/dimensions.

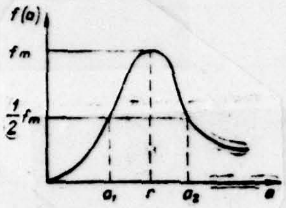

Fig. 11. Typical curve of particle distribution of the water clouds and mist/fogs according to size/dimensions. Along the horizontal axis are plotted the sizes of particles (a - radius of particle), along vertical - a number of particles with the appropriate size/dimensions, or a particle-size distribution function of f(a). Function f(a) has two parameters: the most probable radius of particles r (radius of particles, which corresponds to the maximum of function f(a), in figure - f(m) and the half-width of distribution Δ (width of distribution at the level 1/2fm).

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If we summarize all the studied spectra of the sizes of the particles of the clouds and mist/fogs, then it appears that value r is changed within limits from 0.5 to 10 μ, and the width of distribution - 20-30 times.

The following important characteristics of clouds and mist/fogs are concentration of particles and connected with it liquid-water

content. Usually particle concentration characterizes their number into of 1 cm³, and liquid-water content is measured in grams to cubic meter. Analogously is determined absolute humidity.

With by concentration of particles and liquid-water content is connected also this practically important value, as visibility in cloud or mist/fog. With the same visibility, the concentration of particles and liquid-water content can have the different values. Table 3 gives the values of liquid-water content and concentration of different in sizes particles of the clouds and mist/fogs with the same visibility.

As can be seen from table, with the visibility in cloud or mist/fog, equal to 200 m (by the way, its this most probable value), liquid-water content and particle concentration can differ respectively 20 and 1000 times.

Table 3. Liquid-water content and concentration of particles of different clouds and mist/fogs.

(1) Облака, туман	(2) Величина r, мк	(3) Водность, г/м³	(4) Число частиц в 1 см³
(5) Мелкокапельные	1	0,031 / 0,015	971,0 / 2050,0
(6) Среднекапельные	6	0.194 / 0,101	28,0 / 65,0
(7) Крупнокапельные	10	0,324 / 0,168	10,0 / 2,3

Note. Numerator - most probable value of the parameter Δ, derominator - value Δ, are 5 times smaller than most probable (narrow distributions, characteristic for the initial stage of cloud, either mist/fog or for the specific mist/fogs above airfields).

Key: (1). Cloud, mist/fog. (2). Value r, μ. (3). Liquid-water content, g/m³. (4). Number of particles into of 1 cm³. (5). Light-droplet. (6). Medium-drop. (7). Heavy-droplet.

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The most probable value of water content of clouds and mist/fogs is equal approximately of 0.1 g/m³, i.e., water in cloud or mist/fog is considerably less than is found in vaporous state in the surrounding cloud atmosphere. Let us recall that the absolute humidity in saturation state by the water vapor at temperature of -20°C is equal

to 1.73 g/m^3, at 0°C - 4.845 g/m^3, at 20°C - 17.27 g/m^3.

Mists call the most frequently encountered clouding of the atmosphere by the particles of relatively small size/dimensions with visibility in the atmospheric boundary layer of more than 1-2 km. Perhaps, it is possible to say that mist - this usual state of the atmosphere, in any place and at any time that limiting is the range of visibility in comparison with its value in the pure/clean (Rayleigh) atmosphere, equal to approximately 340 km. The particles cloudying the atmosphere can be liquid, solid, moistened and not wet. Liquid particles have a form of sphere, solid - any form. Most frequently, apparently, meet two-layered particles with solid nucleus and liquid shell. Their form depends on the relationship/ratio of nuclear sizes and shells.

With the contemporary methods of the experimental studies of atmospheric aerosols, to accurately determine the particle shape of the mist is impossible. The data on sizes of particles and their composition also are not characterized by high accuracy. The obtained during experiments data on the microstructure of mist made it possible to isolate three batches of particles: 1) Aitken's nucleus (from 0.001 to 0.1 μ); high particles (from 0.1 to 1.0 μ) and 3) giant particles (more than 1.0 μ).

It is expedient to still introduce the concept of optically active and optically inactive particles. The first include such, which noticeably affect scattering emission/radiation. Scattering the radiation of optically inactive particles can be disregarded. Their maximum size depends on the wavelength of emission/radiation.

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The same particles in different wavelength ranges can be both optically inactive and optically active ones and even maximally optically active ones. As criterion here serves the ratio of particle sizes to the wavelength of emission/radiation. If this sense is close to 0, then we deal with optically inactive particles, if it is close to 1, then particle most effectively scatters emission/radiation.

The analysis of the data on coefficients of scattering for different wavelengths and particle sizes showed that for any wavelength seen and, all the more, the infrared region of particle with the linear dimensions of less than 0.1 μ (Aitken's nucleus) it is possible to consider the as optically inactive. Subsequently we will be interested only in optically active particles.

For the particles of mist and condensation nuclei whose linear dimensions are be greater 0.01 μ, are most frequently characteristic

one-vertex distribution curves with maximum in area of several hundredths of micron. Particle distribution with size/dimensions larger than 0.1 μ is the monotonically decreasing with an increase in the size/dimensions curve. Young it proposed for describing this curve the simple exponential function which has base number - particle size, and index - empirical constant. This distribution is accepted to call distribution Young. As far as value is concerned of empirical constant, it can take values from 2 to 5, depending on time and place. Distribution Young, it goes without saying, very approximately describes real picture, and far not in each specific case to it corresponds the spectrum of particle sizes. However, with different kind calculations researchers, after the lack of another, are forced to utilize distribution Young.

Particle concentration with the size/dimensions of more than 0.1 μ changes within very wide limits both in the atmospheric boundary layer and at different height/altitudes.

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In spite of this, it is possible to call/name some general laws governing a change in the particle concentration with height/altitude. In the lower troposphere usually is observed the rapid exponential decrease of this value. In the upper troposphere is

noted the weak dependence of concentration on height/altitude, then it increases with height/altitude, reaching maximum at height/altitudes from 15 to 23 km, with further increase in the height/altitude, relatively sharply it decreases.

The measurements of particle concentrations at height/altitude it is more than 30 km insufficiently for conclusions about their absolute values and height dependence. However, the fact of presence in the atmosphere of aerosol particles up to the maximum altitudes at which were conducted the investigations (approximately 500 km), does not cause doubts.

There is a number of the investigations in which is revealed the complex dynamic aerosol structure of the atmosphere up to high height/altitudes. Besides the layer of aerosols at height/altitudes from 15 to 23 km, the scientists reveal/detected a series of other, small/finer layers, height/altitude and vertical extent of which is changed. It is completely possible that during the use of new methods of studies, which possess considerably larger accuracy, will be reveal/detected the fine structure of aerosol layers. Is very promising in this plan/layout the method of the laser sounding of the atmosphere.

Residue/settlings always contain large/coarse particles. The

ratio of the sizes of the particles of the residue/settlings to the wavelengths of the visible region of the spectrum is measured by value from hundred to thousands of unity. Table 4 gives data on the parameters of rains of small and large intensity.

Table 4. Parameters of rains.

(1) Дождь	(2) Интенсивность, мм/час	(3) Водность, г/м³	(4) Число капель в 1 м³	(5) Радиус, мм (6) максимальный	(7) наивероятнейший	(8) Коэффициент ослабления, км⁻¹
Слабый (9)	0,3	0,02	80	0,7	0,025	0,10
Сильный (10)	57,0	1,98	19750	3,2	0,3	3,34

Key: (1). Rain. (2). Intensity, mm/h. (3). Liquid-water content, g/m³. (4). Number of drops into of 1 m³. (5). Radius, mm. (6) maximum. (7) most probable. (8). Coefficient of weakening, km⁻¹. (9). Weak. (10). Powerful.

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The overwhelming majority of rains has limits of intensity, indicated in table. Very rarely there are rains of considerably larger intensity. In 1911 in Panama, passed the cloudburst with the intensity of 1360 mm/h, while in 1913 in Sochi, - 224 mm/h.

Particle distribution in residue/settlings according to size/dimensions is described by one-vertex asymmetric curved, analogous curve for clouds and mist/fogs.

Thus, the most frequently encountered types of aerosols (cloud

and mist/fogs, mists, residue/settlings) sharply differ in particle sizes. If for mists are most probable size/dimensions into the hundredths of micron, for mist/fogs and clouds several microns, then in residue/settlings they oscillate from ten to hundreds of microns. In nature can meet the unstable intermediate types of aerosols, for example, during transition from mist to mist/fog or cloud, from cloud without residue/settlings to cloud residue/settlings.

The molecular scattering of optical radiation.

The molecular scattering of optical radiation is is sufficiently well studied over a wide range of wavelengths.

Table 5 gives the values of the coefficients of molecular scattering for temperature of 15°C and pressures 1 atm. (atmospheric boundary layer), and also value of the optical thickness of the vertical layer of the entire atmosphere for a series of wavelengths in range from 0.30 to 1.06 μ.

The coefficient of molecular scattering is inversely proportional to the fourth degree of the wavelength of emission/radiation, and therefore it rapidly decreases in proportion to advance from ultraviolet to to the infrared regions of the spectrum, which distinctly evident also from table.

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Simultaneously with the decrease of coefficient of scattering just as rapidly decreases with wavelength the optical thickness of the vertical column of the atmosphere. Let us note that the optical thickness is the index of exponential function with minus sign, the describing transparency atmosphere. Basis/base in this function exists a Naperian base, i.e., number e=2.7. Thus, if the transparency of an entire thickness of the Rayleigh atmosphere in vertical direction in ultraviolet region for a wavelength 0.30 μ is equal to 29o/o, then for wavelength 0.55 μ, corresponding to maximum sensitivity of human eye, it has already been raised to 91o/o.

In the infrared region of the spectrum, the coefficients of molecular scattering descend to such an extent, that, as a rule, them can be disregarded in comparison with coefficients of aerosol scattering.

Table 5. Values of the coefficients of molecular scattering and of the optical thickness of the vertical layer of the atmosphere for scme wavelengths.

(1) Длина волны, мк	(2) Коэффициент молекулярного рассеяния, $км^{-1}$	(3) Оптическая толща вертикального слоя рэлеевской атмосферы
0,30	$1{,}446 \cdot 10^{-1}$	1,2237
0,40	$4{,}303 \cdot 10^{-2}$	0,3641
0,50	$1{,}716 \cdot 10^{-2}$	0,1452
0,55	$1{,}162 \cdot 10^{-2}$	0,0984
0,60	$8{,}157 \cdot 10^{-3}$	0,0690
0,70	$4{,}364 \cdot 10^{-3}$	0,0369
0,80	$2{,}545 \cdot 10^{-3}$	0,0215
0,90	$1{,}583 \cdot 10^{-3}$	0,0134
1,06	$8{,}458 \cdot 10^{-4}$	0,0072

Key: (1). Wavelength, μ. (2). Coefficient of mclecular scattering, km^{-1}. (3). Optical thickness of vertical layer of Rayleigh atmosphere.

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Energy losses because of the molecular scattering of laser emissicn/radiation do not have a specific character, and the given in table values of coefficients of scattering and cf optical thicknesses it is completely used both to laser ones and to thermal sources.

Scattering of optical waves by aerosols.

In practice usually is utilized the concept of volumetric coefficient of scattering, i.e., the coefficient of particle scattering, included per unit of volume. Its value is determined through the coefficients of scattering the single particles, which are contained in single volume, the particle-size distribution function and concentration of particles (number of particles per unit of volume).

Dispersive medium can consist into some cases of the particles, transparent for the given wavelength of emission/radiation, in other cases of particle, they can absorb the falling/incident on them emission/radiation. Typical example - particle of liquid water. They are transparent in visible range and possess sufficiently powerful absorption in distant infrared region. Therefore the energy losses of the spread in aerosol medium emission/radiation in the general case are composed of strictly wave dissipation on particles because of its refractions, reflections and diffraction and energy absorption of wave by particle itself. If particles are transparent, then we deal with pure scattering, if particles absorbing, besides scattering must be considered and absorption. Thus, in the general case coefficient of scattering more right would be call the coefficient of weakening which is defined as the sum of the coefficients of pure scattering

and absorption. In transparent particles the coefficient of weakening is equal to coefficient of scattering.

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We subsequently will operate with the concept of coefficient of scattering, as is customary, but to imply by it - coefficient of weakening.

The experiments, carried out in the collective of the author, made it possible to draw the conclusion that all data on coefficients of scattering to identical degree were suitable for describing the energy propagation loss in the appropriate aerosols of both incoherent thermal emission/radiation and laser emission/radiation with the same wavelengths. Consequently, for the quantitative estimation of the weakening of laser emission/radiation it is possible to utilize the materials, accumulated for many years of the investigations, carried out, also, before the creation of lasers, and after their appearance.

Scattering by one particle.

The coefficient of scattering the single particle of the spherical form of radius a is the product of its geometric cross

section πa^2 for the so-called efficiency factor of scattering or the function Mu, designated as by $K(\rho, m)$.

The parameter ρ, or parameter Mu, characterizes ratio of particle sizes to the wavelength (λ) of incident radiation ($\rho=2\pi a/\lambda$), and m - the so-called composite refractive index of the material of the particle (in clouds and mist/fogs - particles water or ice). Parameter m consists of two components - real refractive index and absorption coefficient. The first component characterizes the refracting properties of substance, by the second - absorbing.

Function $K(\rho, m)$ is taken from theory Mu. Its exact expression is the infinite, weakly converging series. During calculations of this function a series they break on the definite article, depending on the required accuracy and the value of the parameter ρ. The sense of function $K(\rho, m)$ it is not difficult to understand. Its numerical value determines, what quantity of falling/incident for geometric cross section particle of wave energy is derive/concluded from flow because of scattering (pure scattering plus absorption).

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So, if $K(\rho, m)=1$, then this means that entire/all falling/incident for the section of particle energy is scattered. If $K(\rho, m)>1$ then

particle derive/concludes of the radiant flux more energy, than it falls on its geometric cross section. It is understandable that to each value m corresponds its dependence of this function on parameter Mu (Fig. 12).

Although the concrete/specific/actual form of the function Mu for different composite refractive indices differs, nevertheless some general laws are retained. In all cases with the tendency of the parameter ρ toward 0 function Mu also it approaches 0. This law makes it possible to easily explain the introduced previously concept of optically inactive particles. In fact, the coefficient of scattering one particles is equal to the product of its geometric cross section for function Mu. Hence it is clear that during the decrease of particle size its coefficient of scattering decreases considerably faster than it is proportional to the square of a radius, since on the square of a radius depends the geometric cross section, which is multiplied during the determination of coefficient of scattering by rapidly decreasing function Mu.

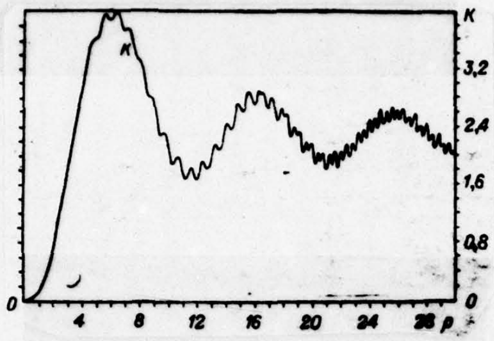

Fig. 12. Form of the function $K(\rho, m)$ at the value of parameter m=1.33 (liquid water in the visible region of the spectrum).

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If the coefficient of scattering small particles (low value of parameter Mu) was defined only by geometric cross section of particles, then in this case one particle with a radius of 10 μ would be scattered light just as 1,000,000 particles with a radius of 0.01 μ. The behavior of function Mu in the region of small ones ρ to larger degree even amplifies the difference in the scattering properties of small and high particles.

Specifically, by this behavior of function Mu it is possible to explain that the fact that the particles of mist weakly scatter emission/radiation in infrared region, particles of clouds and mist/fogs do not virtually detain radio wave. In each the cases we

deal with the low value of parameter Mu and in accordance with the low values of function Mu.

The following general law governing the behavior of function Mu is connected with its increase during an increase in the parameter ρ. This increase and achievement of the first, or the main thing, maximum is observed at all values of parameter m. Principal maximum falls on the values of parameter Mu, by which the linear dimensions of particle have the same order, as wavelength. One should note incomprehensible, at first glance, the torque/moment, connected with the fact that the value of function Mu in principal maximum several times exceeds 1. This means that from the directed radiant flux is derive/concluded energy, several times, that exceeding its value, for the geometric cross section of particle. This interesting fact is connected with the fact that the particle agitates by its presence only not that part of the light wave, which falls directly on it. The passing hereabout from particle emission/radiation also changes its direction of propagation and, therefore, it leaves the directed flow.

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During further increase in the parameter ρ, function Mu decreases, then again it grow/rises, and so forth. The maximums and the minimums become increasingly less and it is less. Within limit at

the high values of parameter Mu, function K(ρ, m) approaches 2 for particles with any value of composite refractive index. Let us note that a quantity of maximums and minimums the dependence of function Mu on the parameter ρ is determined mainly by the value of the absorption coefficient of the material of particle. In the strongly absorbing particles is observed only one principal maximum, and then function K(ρ, m) asimptotically tends for its maximum value equal to to 2. Thus, high particles derive/conclude of the directed energy flow double more than it it falls on their geometric cross section. Again let us emphasize that the concept of high particle relatively. The same particles can be even larger, and small ones, everything depends on the wavelength of the spread emission/radiation. So, the particles of rain are large ones for emit/radiating the visible and close infrared region of the scale of the electromagnetic waves and small ones for radio waves.

On conclusion of this section, let us give the graph/diagrams of the dependence of the refractive index and absorption coefficient of pure/clean liquid water on the wavelength of emission/radiation in range from 0.54 to 25.5 μ (18,520-400 cm^{-1}), obtained by the author and his colleagues.

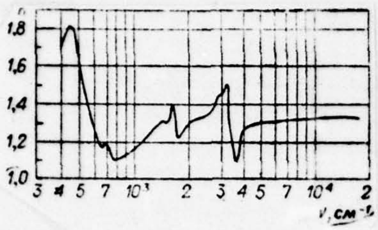

Fig. 13. Dependence of the refractive index of water on wavelength in the region of the spectrum 0.5-25 μ.

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Figure 13 and 14 depicts the refractive index and the coefficient of weakening α, connected with attenuation coefficient by the simple correlation (coefficient α is equal to product from $4\pi\nu$ to absorption coefficient where ν — emission frequency in cm^{-1}).

Along both axes of Fig. 14, are plotted values cm^{-1}, which make completely different sense. Along horizontal axis are represented the emission frequencies, on vertical - the kaysers of the layer of water.

As can be seen from figures, the refractive index of liquid water in the interval of wavelengths in question varies approximately from 1.1 to 1.8 and has 6 more or less clearly expressed maximums and minimums. In the entire visible region of the spectrum, its value is

equal to 1.33. The coefficient of weakening is changed by 6-7 orders, and the designed for the basis of its data absorption coefficient takes values from 0.563 (for a wavelength 17.39 μ) to 0.00,000,016 (for a wavelength 0.558 μ).

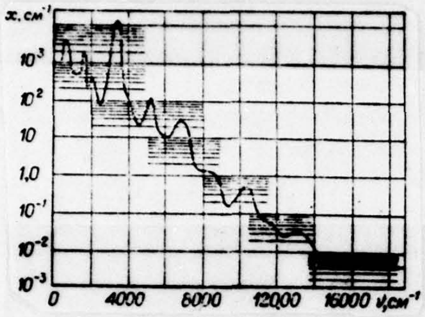

Fig. 14. Dependence of the coefficient of absorption of water on wavelength in the region of the spectrum 0.5-25 μ.

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Volumetric coefficients of scattering clouds and mist/fogs.

The most complete theoretical and experimental data on the volumetric coefficients of scattering liquid-drop clouds and mist/fogs were obtained under author's guidance. We have developed the approximation method of the calculation of volumetric coefficients of scattering, in which they were considered both real particle-size distributions, their concentration and complexity of the refractive index of the material of particles. Moreover precise data on the latter are also obtained in our collective. On the basis of the developed method, was carried out the calculation of the volumetric coefficients of scattering clouds and mist/fogs in the

range of wavelengths from 0.31 to 25.3 μ of all possible values of the parameters of the particle-size distribution function.

For experimental investigations we have created the complex of equipment which made it possible to simultaneously carry out the direct measurements of the volumetric coefficients of water artificial mist/fogs and of all microstructural parameters (particle concentration, the most probable radii and half-widths of distribution).

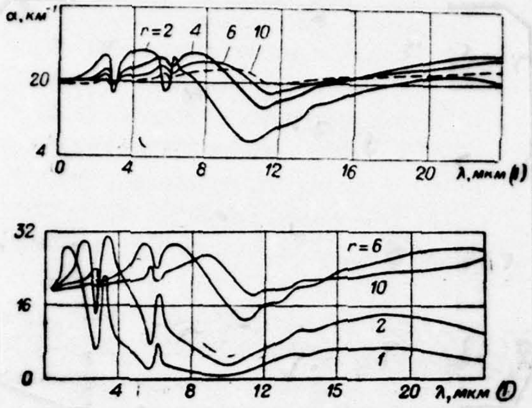

Fig. 15 and 16. Volumetric coefficients of scattering liquid-drop clouds and mist/fogs with the different values of the microstructural parameters at visibility 200 m.

Key: (1) μm.

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Thus, was provided the possibility of the comparison of the measured values of volumetric coefficients of scattering with those designed by the microstructural parameters. The analysis of comparative data testified to the high accuracy of our calculated method and results, obtained with its aid.

Figure 15 and 16 gives some of the results of the calculations of the volumetric coefficients of scattering liquid-drop clouds and

mist/fogs with the different values of the microstructural parameters at visibility 200 m. First figure depicts the curves of the dependences of volumetric coefficients on wavelength in the case of sufficiently wide distribution with the different values of the most probable radius of particles. The second figure demonstrates analogous dependence for narrow distribution.

As can be seen from figures, the heavy-droplet clouds and the mist/fogs (most probable radius is equal to 10 μ) possess the very weakly expressed spectral selectivity of scattering emission/radiation in all investigated wavelength range, in particular during the wide, most frequently encountered in nature particle-size distribution. In proportion to the decrease of the most probable radius and half-width of distribution, the selectivity of the spectral course of coefficients of scattering grow/rises. For example, during narrow distribution and at value of the most probable radius of 1 μ, which can occur in the specific mist/fogs above airfields, the maximum and minimum values of coefficients of scattering differ several dozen times. Moreover area of the smallest values is arrange/located in the range of wavelengths from 8 to 12 μ, i.e., on one hand, it coincides with the long-wave atmospheric window, on the other hand, precisely into this area falls emission/radiation of one of the most promising gas lasers on the mixture of carbon dioxide with nitrogen (most intense

emission/radiation of this laser is observed at wavelengths 10.6 and 9.3 μ).

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Clouds and mist/fogs in the range of wavelengths 0.3-25 μ are extremely insurmountable barrier on the way of the practical use not only of usual thermal sources, but also laser powerful/thick narrow-beam emitters in the atmosphere. Volumetric coefficient of scattering in the most frequently encountered clouds and mist/fogs (most probable radius within the limits of 4-6 μ) in all investigated wavelength range is approximately equal to 20 km^{-1} plus minus several km^{-1} with the most frequently encountered visibility 200 m. But this means that with the passage of parallel radiant flux through the cloud by the extent of 1 km (clouds are and larger vertical power than 1 km, but about horizontal extent and to speak something) it it will be attenuate/weakened 2.7^{20} times ! Is it possible to record emission/radiation after this weakening? The conducted experiments showed that it is possible, but if emission/radiation possesses very small divergence and the field-of-view angle of receiver is equal to the angle of divergence, i.e., speaking in other words, if these highly directional source and receiver preliminarily accurately adjusted and then rigidly attached. Yes even under such conditions recording the emission/radiation, weakened 2.7^{20} times, is close to

the limit of possible.

Consequently, laser sources have the incomparable advantages in comparison with thermal ones. The more precise directionality of powerful/thick laser emission/radiation makes it possible "to break down" the considerably larger thicknesses of clouds and mist/fogs, than this is possible during the use of thermal sources. Furthermore, under specific conditions it is possible to rely on the fact that the powerful/thick laser beam by its effect on cloud or mist/fog will break down to itself path, evaporating the encountered particles. It is completely possible that the supershort momentum/impulse/pulses of laser emission/radiation better traverse aerosol layers than continuous or quasi-continuous emission/radiation.

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Volumetric coefficients of scattering of mists.

From the comparison of the spectra of the sizes of the particles of the clouds and mist/fogs, on one hand, and mists - with another, and the analysis of the dependence of the coefficients of particle scattering on their size/dimensions or parameter Mu, follows the conclusion that for mists the coefficients of scattering must be considerably less than in clouds and mist/fogs. This real/actually thus. Furthermore, it proves to be that the dependence of coefficient of scattering on wavelength in mists is expressed much more clearly than in the case of clouds and mist/fogs. For illustration we give the graph/diagram of the dependence of coefficient of scattering in mists with the different value of meteorological visual range from 1 to 50 km in the interval of wavelengths 0.3-25 μ for the most frequently encountered spectra of the particle sizes, described by formula Young (Fig. 17). Curve/graph is constructed on the basis of the calculations, carried out by the author with his colleagues.

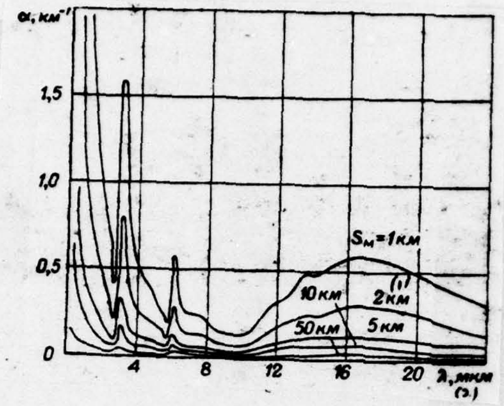

Fig. 17. Graph/diagram of the dependence of the coefficient of scattering on wavelength in mists of the different values of meteorclogical visual range.

Key: (1). km. (2). μm.

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In the calculations of the values of the coefficients of scattering mists, was considered the complexity of the refractive index of the particles of the mists which were considered the as water spheres. Thus, the obtained values of coefficients consider pure scattering on particles, and the absorption by them of emission/radiation. The data on the composite refractive indices of water were obtained in our collective. For the minimum and maximum sizes of particles, were undertaken particles with the radii, equal

to 0.05 and 5.0 μ.

Let us comment the depicted in figure curves of the spectral dependence of the coefficients of scattering of different visibilities. First of all strikes the sharp decrease of the coefficients of scattering during an increase in the wavelength from 0.3 to 2.7 μ. (Value of coefficient of scattering in this interval decreases 16 times). This sharp decrease caused by the appropriate decrease of parameter Mu in function $K(\rho>m)$ explains the advisability of using the yellow filters in usual photograph. Such filters "cut" the most intense phon of mist in ultraviolet region and in violet-green part of visible spectrum. If the sensitivity of the generally accepted photographic materials in red region was still above, then one ought not to have applied not *yellow, but red* filters. In infrared photograph it is possible to achieve the even better results during photographing of the hidden by mist distant objects because of the sharp decrease of coefficients of scattering.

Let us observe further behavior of coefficients of scattering in mists with an increase in the wavelength. In Fig. 17 we see two sharp narrow maximums in area of wavelengths of approximately 2.9 and 6.0 μ and one steady wide maximum with center approximately 17 μ. They are due by their origin to the appropriate maximums in the spectral curve of the absorption coefficient of liquid water.

In the region of the long-wave atmospheric window - innermost minimum cf the coefficient of scattering mists.

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The numerical values of the coefficients of scattering mists in region 0.3-25.3 μ are given in table 6, comprised for the most probable values of the parameters of microstructure (minimum and maximum sizes of particles 0.05 and 5.0 μ on a radius, exponent in distribution Young it is equal to 4, visibility in atmospheric boundary layer 10 km). Coefficients of scattering for other visibilities in the atmosphere it is easy to obtain from these these, taking into account the inverse proportionality of these values.

Thus, the most frequently encountered mists have coefficients of scattering, which differ for different wavelengths more than 60 times (maximum value for a wavelength 0.3 and minimum in area 8-11 μ). However, the maximum value of coefficient of scattering is more than by an order of less than the minimum value cf the coefficient of scattering the most frequently encountered clouds and mist/fogs.

Thus, mists are considerably more transparent than clouds and mist/fogs in all the investigated range of wavelengths. But an especially large difference in coefficients of scattering in area of the long-wave atmospheric window: here it it reaches three orders !

Table 6. Values of the coefficients of scattering mists in region 0.3-25.3 μ.

Длина волны излучения, мк (1)	Коэффициент рассеяния, км−1 (2)	Длина волны излучения, мк (1)	Коэффициент рассеяния, км−1 (2)	Длина волны излучения, мк (1)	Коэффициент рассеяния, км−1 (2)
0,31	0,65	0,84	0,24	5,27	0,03
0,50	0,40	1,06	0,18	8,36	0,01
0,53	0,38	1,15	0,17	10,60	0,01
0,63	0,32	2,36	0,07	25,31	0,02
0,69	0,29	4,55	0,04	—	—

Key: (1). Wavelength of emission/radiation, μ. (2). Coefficient of scattering, km^{-1}.

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Let us note that the made above conclusion/derivations are instituted on results of the calculation, carried out by us on the basis of two assumptions: 1) the particle of mist - these are water spheres and 2) the spectrum of their size/dimensions is described by empirical formula Young. Strictly speaking, the results of calculation are inapplicable to mists which consist not only of liquid-drop, but also two-layered particles with solid nuclei or of the solid particles of irregular form. However, the two-layer nature of particles does not have vital importance, if the size/dimensions of solid nuclei are less than the size/dimensions of shells, which

usually has the place. If the particle cf mist cf nonspherical form, then the given above results of calculations can be considered as certain apprcach/approximation to actuality; this degree of approximaticn it is caused mainly not by particle shape, but by the possible difference in the composite refractive indices of liquid and sclid aeroscls. Our conducted in collective calculations of the coefficients of scattering the ellipsoidal water particles, chactically oriented in space, they showed, that their coefficients of scattering differ little frcm the coefficients of scattering of the water spheres cf equivalent size/dimensions.

Fcrmula Young very approximately describes the real spectra of the sizes of the particles cf the mists. Therefcre in each specific case ccefficients cf scattering, generally speaking, must differ from those designed with the application/use of a formula Young. However, to calculate coefficients of scattering for the real spectra thus far is impcssible for lack in the corresponding data on the particle-size distribution functions.

The scarce experimental data on the coefficients of scattering mists mainly in the visible and clcse the infrared regions of the spectrum are in the qualitative agreement with data of our calculations. About quantitative agreement it is not necessary to speak, since in all carried out until recently experimental

investigations the parameters of the microstructure of mists were not measured.

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Let us note that in our calculations were taken the different values of the parameters of the microstructure of mists (different minimum and maximum sizes of particles and indices in the exponential function of formula Young). It is reveal/detected that the spectral course of coefficients of scattering is most sensitive to the index of exponential function. The decrease of the minimal size of particles does not lead to substantial changes in the coefficients of scattering, that again confirms the presence of optically inactive particles. Indeed the decrease of the minimal sizes of particles will automatically entail the inclusion into calculation to the rapid degree of an increasing multitude of small/fine particles.

Let us give that constructed on the basis of the data of table 6 on the coefficients of scattering the curve/graphs of the dependence of the aerosol component of spectral transmittance of atmospheric boundary layer for the distances of the propagation of radiation 1.10 and 50 km. Curve/graph visually illustrates the energy losses of emission/radiation and does not need supplementary commentaries (Fig. 18).

Figures 19, 20 depict the dependences of the component of transparency mist in vertical direction on wavelength in the interval of 0.3-25 μ, constructed according to data our calculation.

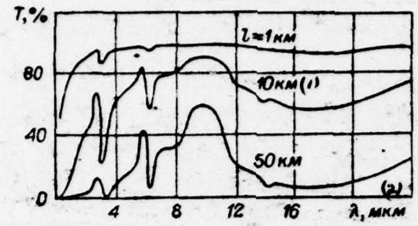

Fig. 18. The spectral transmittance of mist in the range of wavelengths 0.3-25 μ with meteorological visual range 10 km; with $\beta=4$, $\alpha_1=0.05$, $\alpha_2=5.0$ μ.

Key: (1). km. (2). μm.

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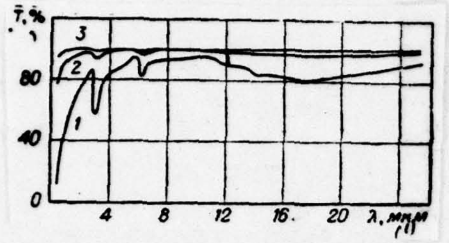
In this calculation was considered the exponential decrease of the optically active particles of the mist with height/altitude and it was assumed that the spectra of size/dimensions with height/altitude do not change. In other respects the calculation was performed just as for an atmospheric boundary layer. Figure 19 shows the spectral transmittance of mist in the vertical direction of the lower 5-kilometer layer of the atmosphere for those cases when visibility in the lowest layer of the atmosphere was equal to 1.10 and 50 km. Upper curve in Fig. 20 characterizes the spectral transmittance of the lower half-kilometer layer of the atmosphere with visibility in

the Earth, equal to 5 km. Lower curve is obtained for the lower 5-kilometer layer of the atmosphere under the same visibility conditions in the Earth. Both curves are related to the vertical layers of the atmosphere.



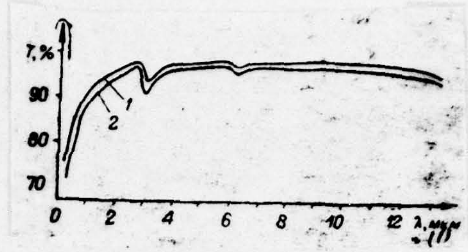


Fig. 19. The spectral transmittance of mist in the vertical direction of the lower five-kilometer layer of the atmosphere with the meteorological visual range 1.10 and 50 km.

Key: (1). µm.

Fig. 20. Spectral transmittance of mist in vertical direction for layers of atmosphere: 1) 0-0.5 km; 2) 0-5.0 km with meteorological visual range 5 km.

Key: (1). µm.

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The comparison of last/latter three figures shows that haze in vertical direction is much more transparent than in atmospheric boundary layer. The preferred portion of the weakening of emission/radiation by mist in vertical direction falls on the lower

half-kilometer layer of the atmosphere.

Coefficients of scattering residue/settlings.

Inasmuch as the particle of residue/settlings for the wavelengths of emission/radiation in visible, close and average the infrared regions of the spectrum can be considered as large ones, any particle, without depending on its size/dimensions, has an efficiency factor of scattering, equal to 2. Hence automatically follows the conclusion that the coefficients of scattering residue/settlings in the which interests us wavelength range have neutral spectral course, and the absolute value of volumetric coefficients of scattering is equal to the doubled geometric cross section of particles per unit of volume.

The conducted experimental investigations of the coefficients of scattering residue/settlings (rains and snowfalls) showed that their value is sufficiently unambiguously determined by intensity or water content of residue/settlings in complete agreement with theoretical expectations. The absolute value of the coefficient of scattering of intensity of rainfall 10 mm/h (average value) is approximately equal to 1 km^{-1}. On path 1 km, this rain will attenuate/weaken emission/radiation by approximately 60o/o.

In spite of theoretical forecasts, carried out under the guidance of the author of measurement in visible range and in area of the long-wave atmospheric window it became the different values of coefficients of scattering.

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However, as testifies the detailed analysis of these results, their contradiction to theory proved to be that seeming. Its reasons consist of the so-called indicatrix effect.

Diagrams, or indicatrices of scattering.

Until now, we examined the energy losses of optical waves during their propagation through the atmosphere as dispersive medium, independent of the distribution of the scattered or lost energy with respect to the direction of propagation of emission/radiation. But this distribution there is exactly the indicatrix (diagram) of scattering. Coefficient of scattering summarizes in itself the energy loss, scattered in all directions, i.e., coefficient of scattering is obtained as a result of integrating the indicatrix of scattering. And if us does interest only total quantity of leaving from the directed energy flow, then not all is equal, as are distributed these losses on scattering angles?

However, for a large quantity of scientific and applied problems of optics of the atmosphere and the connected with it directions of science and technology, it is entirely significant, which diagram, or indicatrix of scattering. Scattering angles it is usually accepted to count off from the direction of propagation of emission/radiation, i.e., if we speak about forward scattering and backward scattering, then there are in form scattering angles, close to 0 and 180°.

For molecular (Rayleigh) scattering the indicatrix is symmetrical (Fig. 21) to direction of propagation. This means that at angles of 0 and 180; 90 and 270; 45, 135, 215 and by 325° and so forth is scattered the identical energy content.

Entirely appear in another way the indicatrices of scattering of aerosol particles. Let us examine this picture based on the example of the well studied spherical particles.

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Only small particles with the value of composite refractive index, close to 1, and in parameter Mu→0 have analogous Rayleigh symmetrical indicatrix of scattering (these particles resemble the random

localized volumes of the increased air density, calling molecular scattering of light). But the already small absolutely reflecting particles have an indicatrix, sharply elongated back/ago. It attests to the fact that for such particles the large part of the scattered energy is directed to rear hemisphere, besides predominantly at the angles, close to 180°. It should be noted that among natural atmospheric aerosols there are no absolutely reflecting or close to them particles. Different researchers for the particles of the atmospheric aerosols in the visible region of the spectrum take the value of refractive index, included in range from 1.33 to 1.50.

In proportion to growth of parameter Mu from 0 to ∞ indicatrix of spherical particles continuously changes its form, becoming ever more and more elongated forward (effect Mu). Figure 22 depicts the indicatrices of scattering of particles with the different values of the parameter ρ. Let us give the example, which illustrates a change in the elongation of the indicatrix of transparent particles with a refractive index 1.5 and with a radius of 0.5; 1.5; 5.0 and 12.5 μ for the wavelength of emission/radiation 0.5 μ.

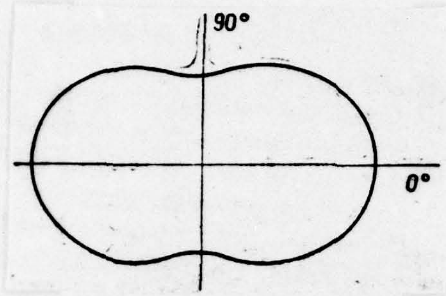

Fig. 21. Indicatrix of molecular (Rayleigh) scattering.

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It is not difficult to calculate, that the parameter ρ in this example is equal to 6.28, 18.84; 62.8 and 157. Ratio/relation scattered into the front/leading and rear hemisphere of emission/radiation, or the coefficient of asymmetry of indicatrix of scattering, is respectively equal to 17; 74; 823 and 16000. Let us note that in our example are undertaken the real aerosol particles (first two numerals are characteristic for the particles of the mists, second two - for the particles of the clouds and mist/fogs).

On a change in the form of indicatrix of scattering with a change in the particle sizes, has effect the complexity of the refractive index of the material of particles. Furthermore, if the calculation of the indicatrices of news with low pitch on value ρ,

are detected rapidly increasing with an increase in the scattering angle of the oscillation of the values of the intensity of that scattered at this angle of radiation. In nature they no value have, since virtually disappear in the indicatrix of scattering of real pclydisperse aerosol, i.e., the aeroscl, which consists of the particles cf different size/dimensions.

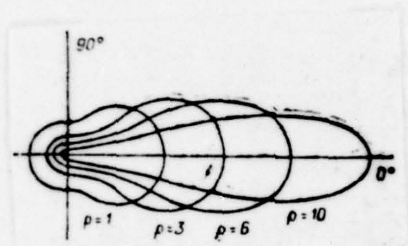

Fig. 22. Indicatrices of scattering of particles with the different values of the parameter ρ.

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LIMITS OF THE APPLICABILITY OF THE EXPONENTIAL LAW OF FADING.

The value of the coefficient of scattering, multiplied by the distance, passable by emission/radiation in medium, gives the optical thickness of layer which enters into the index of the exponential law of fading (weakening) emission/radiation because of scattering. In the presence of the data on coefficient of scattering, we easily can forecast forecast the transparency of any layer of dispersive medium, if they are confident in the applicability of the exponential law of fading.

The author with the colleagues of the institute of optics of the atmosphere carried out the extensive studies of the limits of the

applicability of this law for different dispersive media and radiation sources. Special attention was given to the laser radiation sources. Let us examine the basic reasons for the disturbance/breakdown of the exponential law of fading which is derived from the assumption that the particles of medium scatter world/light independently one from another. This assumption is confirmed, if we disregard multiple scattering of world/light during its propagation in medium. If world/light before covering a distance from source to receiver, tested two, three and so forth of the event/report of scattering on particles, then they speak about double, triple and so forth scattering.

Multiple scattering will be exhibited with the smaller values of optical thicknesses, but at the assigned value of the coefficient of scattering with respect to those smaller values of the way of emission/radiation, than wider radiation source we will examine. So, with the overcast we deal mainly with the repeatedly scattered sunlight. If this was not, then on the Earth there would be the desperate dark. In fact, the coefficient of scattering the most frequently encountered clouds is equal to approximately 20 km^{-1}. This means that with the vertical extent of cloud 1 km the passed through it direct/straight solar radiation is attenuate/weakened 2.7^{20} times !

For narrow laser sources one should expect the perceptible effect of multiple scattering only with the very large depths of penetration of emission/radiation into dispersive medium, let us say, into the same cloud.

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Together with true divergence from the exponential law of fading, caused effect of multiple scattering, in practice for us it is necessary to observe the apparent divergence from this law, connected with the limited possibilities of metering equipment. Discussion deals with the effect of this equipment on the results of the measurements of coefficients of scattering. Their measured values can differ from true ones, predicted by correct theory.

Coefficient of scattering considers energy losses, by the scattered each particle in different directions. For determining the coefficients of scattering during experimental investigations, we cannot create the installation which did not record part scattered by the particles of energy. Any receiving system has the different from 0 field-of-view angle within limits of which it simultaneously records the weakened, exponentially, emission/radiation, and counterpart of scattered radiation. The lesser the field-of-view angle of receiving system, the lesser it records scattered radiation.

In such a manner, however we tried, experimentally it is not possible to determine true coefficient of scattering, since measurements are always to a certain degree burdend by the effect of recorded by receiver scattered radiation.

The effect of metering equipment on the results of the measurements of coefficient of scattering depends on the geometric parameters of source and radiation detector and indicatrix of scattering of medium. It is clear that the measured coefficient of scattering the greater will differ from true, the greater the visual angle of receiver, the angle of the divergence of source and the elongation of indicatrix of scattering.

In practice during the study of the laws governing scattering directional radiation in dispersive medium, it is necessary to deal with the simultaneous recording of the direct radiation, weakened exponentially of fading, and also - repeatedly and once scattered forward radiation.

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Usually direct radiation bears on itself some useful information, and, thus far its brightness exceeds the brightness of the background, created by forward scattering, information can be

accepted and deciphered. But if the brightness of background becomes equal to the brightness of direct radiation or exceeds it, then to isolate useful information from the emission/radiation accepted is already impossible, since scattered radiation is created by spread light beam itself. On the other hand, if the recorded by receiver brightness of the background of scattered radiation is much less than the brightness of direct radiation, then the exponential law of fading can be considered valid. Thus, the knowledge of the limits of the applicability of this law acquires important practical value.

The conducted by us investigations of the limits of the applicability of the exponential law of fading in different dispersive media made it possible to make following basic conclusions. If the angle of the divergence of radiation source does not exceed 6 angular minutes and is equal to the field-of-view angle of receiving system, then for all types of atmospheric aerosols the exponential law of fading remains valid up to the maximum optical thicknesses which were reached in experiments. The maximum optical thickness with which still it was possible to confidently record the weakened signal in mist/fog, was equal to 25, therefore, was recorded the signal, weakened 2.7^{25} times ! The majorities of laser sources have an angle of divergence within the limits of 6 angular minutes, and if we in work with them utilize receiving systems with the field-of-view angle, equal to the divergence of source, then it is

possible tc be assured in the applicability of the exponential law of fading up tc the largest optical thicknesses which still can be "X-rayed" in any of the atmospheric aercsels.

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During the study of the propagaticn of laser emission/radiation in the aerosol atmosphere, is of interest nct cnly evaluation of the energy losses of emission/radiation because of scattering on different types of aerosols. Until now, we examined precisely these questicns. Important practical value have the studies of the laws governing scattering emissicn/radiation at different angles and first of all scattering at small angles (forward scattering) and at the angles, clcse to 180° (backward scattering), since most essential effect cn the work cf lasers in the communication systems, transmission of the information, lccaticn and cthers first of all have fcrward and backward scatterings. Also there is great interest in the study of unsteady scattering, i.e., scattering the short laser pulses, which are used in location, during sounding of the atmosphere, during the ultra-precise determination of distance of the distant objects. Finally, during the solution of a series of applied problems can prove to be highly useful infcrmation about the effect cf the atmcsphere on the polarizational characteristics of the spread in it emission/radiaticn.

SCATTERING OF LASER RADIATION IN FOWARD DIRECTIONS AND BACK.

The purpose of our carried out in collective investigations of scattered at small angles in foward directions and back laser radiation consisted in obtaining of the necessary data on the brightness of scattering. The results of the experimental studies of the brightness of scattered forward radiation were used for the determination of the limits of the applicability of the exponential law of fading.

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For the illustration of some from the obtained results of the experimental studies of the brightness of scattered forward radiation in mist/fogs and wood fumes, we give Fig. 23, in which along the horizontal axis are plotted the optical thicknesses, passable by the emission/radiations of gas laser on the mixture of helium with neon (wavelength 0.63 μ) and solid-body laser on ruby, which worked in the conditions/mode of free generation (wavelength 0.69 μ); along vertical axis - brightness of emission/radiation in logarithmic scale. Continuous straight line in figure depicts a reduction in the

trightress of the direct radiation, weakened exponentially. Points and crosses designated the results of brightness measurements of scattered forward radiation respectively ir mist/fogs and fumes. Let us ncte that the sizes of the particles of wood smoke approximately correspond to the average particle sizes of the mist.

As can be seen frcm figure, the brightress of scattered forward radiaticn both in mist/fogs and in fumes has a maximum in area of the value of the optical thickness, equal to 1. In all interval of the investigated optical thicknesses, the brightness of scattered forward radiation in mist/fogs to 1-1.5 orders is mcre than in fumes, which is not difficult to explain by the appropriate difference in indicatrices of scattering.

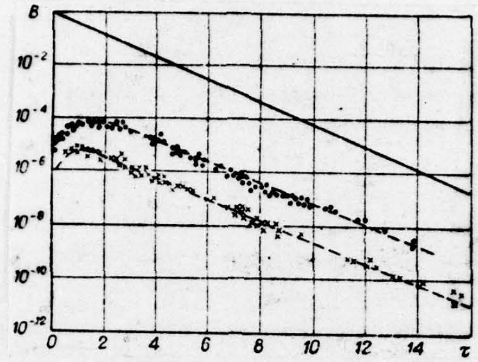

Fig. 23. Dependence of the brightness cf scattered forward radiation cn optical thickness in mist/fogs (point) and mists (crosses). Dotted curves are constructed on the basis of calculations according to the theory of single scattering, straight line describes the weakening of direct radiation exponentially.

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For the used in experiment in experiment wavelengths of the emission/radiation of the indicatrix of scattering of mist/fogs, it is inccmparably more elongated forward, than for fumes, and this leads to the fact that one and the same receiver receiver in the case cf mist/fogs records considerably the more scattered forward radiation, than in the case of fumes. Up to the limiting values of the optical thicknesses which in the described experiment were equal to 14-16, the brightness cf scattered forward radiation in mist/fogs

and fumes was less than the brightness of direct radiation respectively to 2-3 and 4-5 orders.

During the experimental studies of the brightness back-scattered emission/radiation by mist/fogs and fumes were utilized the lasers at wavelengths 0.63 and 0.69 μ. During measurements under natural conditions in fumes and snowfalls, was utilized the solid-body laser on glass with neodymium, which worked in the conditions/mode of free generation (wavelength of emission/radiation 1.06 μ). The obtained results are reduced to following.

The brightness back-scattered emission/radiation in mist/fogs during an increase in the optical thickness from 0 to 1 grow/rises, remaining to 8-9 orders of less than the initial brightness of incident radiation. Then it relatively slowly it decreases in the interval of values optical of thickness 1-8 it remains in effect constant with the high values of optical thickness. Since the brightness of direct radiation decreases exponentially, with an increase of optical thickness difference in the values of brightnesses back-scattered and direct radiation is gradually decreased and disappears completely upon reaching of the optical thickness, approximately equal to 22 in our experiments. The brightness back-scattered emission/radiation with large optical thicknesses in mist/fogs and fumes coincides.

Under natural conditiors in mists with the range of visibility frem 3 to 7 km, the brightness of backscattering composes approximately 10^{-10} brightnesses of initial emission/radiation. The appearance of snowfalls does not virtually change the intensity of the echo from the particles of the mist sigral.

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This is not difficult to understand, if one considers that the concentration of snowflakes is considerably less than the concentraticn of particles of the mist, and the indicatrix of scattering of snowflakes is substantially mcre elongated forward, than in the particles of the mist.

POLARIZATIONAL CHARACTERISTICS OF SCATTERED LASER RADIATION.

The state of the polarization of scattered at different angles of radiaticn has the important value during the solution of many applied problems, connected with the transmissicn of one or the other information through the atmosphere with the aid of laser emission/radiation. In fact, if dispersive medium is irradiated by

the plane-polarized laser emission, its particle, generally speaking, can depolarize emission/radiation during scattering. Polarizational equipment/devices, if they are are utilized with the method of emission/radiation, are capable of ensuring the unimpeded passage of direct radiation and of delaying the considerable portion of scattered radiation. This can increase the range of the corresponding equipment/device. So calculations they show that the use of polaroids in receiving systems can increase visibility under water at least double. Analogous effect can be expected, also, in the atmosphere.

There is greatest practical interest in the study of the polarizational characteristics of the laser emission/radiation, scattered in foward directions and back/ago. Some results of this type of investigations are obtained in the collective of the author. As radiation source, was utilized gas laser in wavelength 0.63 μ. Investigations are carried out in two dispersive media, liquid-drop mist/fogs and wood smoke. For both of media, is not reveal/detected the depolarization of the emission/radiation, scattered in the direction forward.

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On the contrary, the noticeable depolarization back-scattered emission/radiation is observed in each media already at the value of

the optical thickness of scattering layer, equal to 0.5 (it is equal in this case to 25 and 30o/c respectively in mist/fogs and fumes). During an increase in the optical thickness, the polarization back-scattered emission/radiation linearly decreases, besides it is more rapidly in mist/fogs, than in fumes. So, at the value of the optical thickness, equal to 6, it approximately composes in mist/fogs 35, in fumes - 45o/c. Experiments showed that the degree of polarization back-scattered emission/radiation does not virtually depend on the angle of the divergence of the source when it is changed within limits from 40 seconds of arc to 6 angular minutes.

PROPAGATION OF SHORT LASER PULSES IN DISPERSIVE MEDIA.

The use of lasers in systems of location, equipment/devices for the ultra-precise determination of distance of the distant object/subjects, during sounding of the atmosphere requires the knowledge of the laws governing the propagation of short laser pulses in the atmosphere. Real/actually, if for example, short laser pulse with duration in nanosecond is sent in the direction of the object, then this momentum/impulse/pulse twice passes path in the atmosphere from source to object and vice versa. In the absence of atmosphere (for example, when measurement they are carried out in kosmos), the accuracy of the determination of object distance is determined by the

slope/transconductance of leading impulse front and its duration. In the atmosphere the momentum/impulse/pulse can undergo the considerable changes without taking into account of which it is difficult to be that assured in the accuracy of measurements. During propagation in the atmosphere, short laser pulse diffuses, it is deformed, and the degree of this strain must depend on the character of medium.

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Let us give some results of our experimental and theoretical studies, dedicated to this question, having been preliminarily specified, that the problem of unsteady scattering is located thus far even in the initial stage of its solution.

By us were studied the oscillograms of the echo from water artificial mist/fogs laser pulse of semiconductor generator on gallium arsenide in wavelength of emission/radiation 0.84 μ at the values of coefficients of scattering the respectively equal to 1.5; 0.84; 0.43; 0.25; 0.13 and 0.08 m^{-1}. The duration of launched pulse was equal to 8 ns with the amplitude, equal to the half of maximum, the scale value of the vertical lines of screen was equal to 10 ns. Receiver and source were arrange/located so that their optical axes intersected within the medium being investigated at angle of 1° at a

distance of 7 m of front/leading boundary.

Oscillograms distinctly showed a regular change in the width, delay time and in maximum amplitude of the echo pulse in proportion to a change in the coefficient of scattering, or that nevertheless, the density of mist/fog. The denser the mist/fog, the lesser diffuses in it the echo pulse, since it is form/shaped in with respect smaller thicker.

Figure 24 depicts the results of the calculations of the strain of the instantaneous momentum/impulse/pulse, which passed through the liquid-drop cloud with the optical thickness, equal to 5. Calculation is carried out with the use of a method of statistical tests for a source with the initial diameter of 8 mm, the angle of the divergence of 30 angular minutes, the wavelength of emission/radiation 0.7 μ. In figure represented angular flow distribution of photons in the plane of the receiver with a diameter of 150 mm whose axis coincides with the axis of source. Curve 1 describes a quantity of photons which fly for first 10 ns at the different angles through the plane of receiver; curves 2, 3, 4 - reflect the same picture, but into the following time intervals, on 10 ns each.

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Let us recall that the discussion deals with the propagation of the instantaneous momentum/impulse/pulse which, do not be on its path of dispersive medium, it must without deliquescence pass path from source to receiver.

As can be seen from figure, the overwhelming majority of the photons of instantaneous momentum/impulse/pulse reaches the receiver in the time interval of 10 nanoseconds, besides, as one would expect, their bulk flies into receiver at the angles, close to normal.

The used during calculations method of statistical tests, or as it still call, the Monte-Carlo method, it makes it possible to obtain the complete picture of the scattered light field during the propagation of both instantaneous momentum/impulse/pulses and momentum/impulse/pulses with the assigned duration in any dispersive media, if are known their coefficients of scattering and indicatrix of scattering for the appropriate wavelengths.

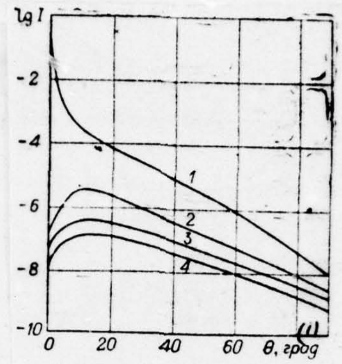

Fig. 24. Calculation of the strain of the instantaneous momentum/impulse/pulse, which passed through the liquid-drop cloud.

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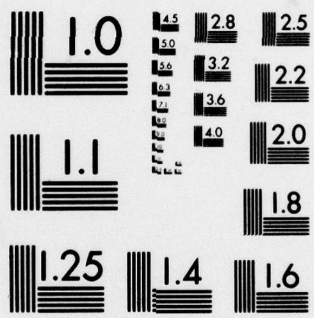

MICROCOPY RESOLUTION TEST CHART

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Chapter Four.

LASER BEAM IN A TURBULENT ATMOSPHERE.

Heterogeneities of the refractive index of air.

The earth's atmosphere is simultaneously the absorbing, scattering and turbulent medium. The spread in it optical radiation, besides energy losses because of absorption and scattering, experience/tests the fluctuations, caused by random changes in the refractive index of medium. Atmosphere mixing as a result of turbulent air motion leads to the fluctuations of the values of the temperatures which in turn, cause the fluctuations of the refractive index of air.

Calculations show that a change in the temperature of air on 1°C changes the index of its refraction to the value of the order of the millionth portion. The amplitude of the observed fluctuations of the temperature at the particular point reaches the tenths of degree, and

the period of pulsations is included within limits from milliseconds to whole seconds. The amplitude of the fluctuations of the temperature in the horizontal plane of the atmosphere for the points, arrange/located at a distance from hundred to thousands of meters, can reach several degrees.

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As a result of turbulent motions in the atmosphere, are created the random heterogeneities whose size/dimensions vary from hundred and more than meters (macroheterogeneity) to centimeters and millimeters (microheterogeneity). Microheterogeneities near terrestrial surface have size/dimensions of approximately 1 mm.

During the propagation of laser emission/radiation through such random heterogeneities the energy in beam section, it will experience/test random redistributions. Let us present laser beam in that consisting of the separate ray/beams, which evenly fill entire cone of the emission/radiation at the output of source. Each of the ray/beams during propagation through the turbulent atmosphere will randomly change their trajectory. As a result, if we examine the beam section at some distance from source, we is reveal/detected spotty, often dynamic structure in intensity distribution of emission/radiation. The position of bright and dark places into beam

section for each torque/moment of time - its inherent, unrepeatable.

If the area of receiving mirror utilized during recording of past through the atmosphere of emission/radiation, composes some part of the beam section, then the recorded signal will experience/test continuous fluctuations, since to mirror at each moment of time will fall the different energy content.

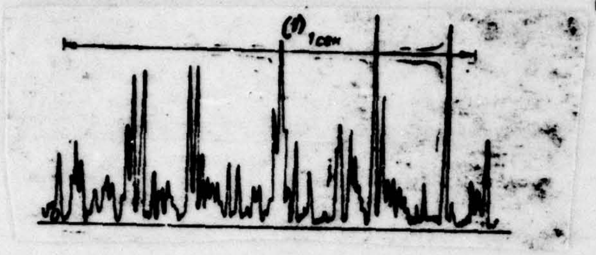

Fig. 25. The example of the recording of the fluctuation of the signal, which is spread through the turbulent atmosphere for the case, when receiving mirror does not intercept beam.

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Let us give the example of the recording of the fluctuation of the signal, which is spread through the turbulent atmosphere, for the case when receiving mirror does not intercept beam (Fig. 25). As can be seen from figure, for second the signal tested about hundred of fluctuations with very imposing amplitude.

During propagation in the turbulent atmosphere, laser emission/radiation can experience/test different changes: the redistribution of intensity in beam section (space-time fluctuation of intensity); a change of the cross section, or the diameter of beam, divergence of beam as whole from direction rectilinear

propagation; the fluctuation of the angle of arrival of emission/radiation in the focal plane of receiving optical system; a change in the coherence of emission/radiation. Let us examine each of these phenomena.

Fluctuations of intensity.

The value, which characterizes the fluctuations of intensity, is called the dispersion of fluctuations. It indicates the divergence of the measured values of intensity from average. If, for example, the dispersion of fluctuations is equal to 1, this means that the scatter of the separate values of the measured signals with respect to average signal is within the limits by ±100o/o.

The value of the dispersion of the fluctuation of intensity depends on meteorological conditions, optical path length of ray/beam, geometric parameters of light beam, diameter of receiving mirror, the time constant of receiver, wavelength of the emission/radiation of beam.

The fluctuations of the intensity of the emission/radiation, which is spread in the turbulent atmosphere, it is accepted to divide into weak and powerful ones in conformity with the values of the dispersion of fluctuations.

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For weak fluctuations is developed theory, which allows with greater or by smaller authenticity to describe the observing in experiments facts. The theory of powerful fluctuations is located even in the stage of development. The study of powerful fluctuations is of greatest practical interest, since they appear during the propagation of emission/radiation up to large distances. Furthermore, precisely, powerful fluctuations most limit the use of lasers in different equipment/devices, intended for the work through the atmosphere.

Let us examine the most important dependences of the dispersion of the fluctuations of intensity on different parameters. As the first parameter let us take the distance, passable by light beam in the atmosphere, which was repeatedly investigated experimentally, including in the collective of the author. These investigations reveal/detect/exposed the following general law: with an increase in the distance, the dispersion of the fluctuations of intensity smoothly increases, and then remains constant or slowly decreases. The distances, at which is reached maximum value and its value in different researchers, are not identical, since measurements were conducted under different meteorological conditions and with

different equipment.

The studies of the dependence of the fluctuations of the intensity of laser emission/radiation from the diameter of receiving mirror establish/installed the steady decrease of the dispersion of the fluctuations of intensity with an increase in the diameter of receiving mirror to the specific value. Further increase in the diameter did not virtually lead to a change in the dispersion of the fluctuations of intensity.

This fact can be explained as follows. When the diameter of receiving mirror has value of the same order as as average sizes of spots with the maximum and minimum intensity of emission/radiation in beam section, then, obviously, and the dispersions of the fluctuations of intensity have maximum value.

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With an increase in the diameter of receiving mirror by its area at each moment of time, falls a increasing quantity of light and dark spots. This, in the final analysis, and it leads to the fact that, beginning with certain size/dimension of mirror, further increase does not lead to an increase in the dispersion of the fluctuation of intensity until the size/dimension of mirror achieves the value, with

which the beam will be completely intercepted. In this case, the dispersion of fluctuations decreases by jump, but not to 0, as it was possible to expect. This, if one may put it that way, remanent/residual fluctuation is due by its existence to the fluctuations of the brightness of the background, which appears during forward scattering on the particles of aerosol.

The study of the dependence of the dispersion of the fluctuations of intensity on the angle of the divergence of radiation source showed that it is a curve with the wide and shallow minimum, which attests to the fact that the dispersion of the fluctuations of intensity has the minimum value at the specific angle of the divergence of source.

Several words about the frequency spectrum of the fluctuations of intensity. Entire spectrum, as show the data of experimental studies, stretches from the portions of hertz to 1-2 kHz; however, the band of the most frequently encountered frequencies of the fluctuations is included within limits from several ones of ten to several hundred hertz. Specifically, in this area is placed the maximum of the frequency spectrum of the fluctuations of intensity.

Fluctuation of the diameter of beam.

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During propagation in the turbulent atmosphere of laser emission/radiation, the diameter the yoke of beam experience/tests certain expansion, supplementary in comparison with the expansion, caused by geometric and diffraction divergence of beam. This expansion somewhat grow/rises with distance.

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So, with one of measurements at distances of 15 and 145 km was observed an increase in the divergence of beam by 8 and 13 seconds of arc respectively.

In the conducted under author's guidance investigations were reveal/detected the considerably larger fluctuations of the diameter of the beam of laser on ruby during recording of emission/radiation at one and the same distance, namely - 10 km.

The effect of the turbulent state of the atmosphere on expansion of the diameter of the beam of laser emission/radiation has very important practical value with the beam focusing of emission/radiation in the atmosphere. It is known that during propagation in vacuum between the diameters of the focused and initial beams there is an inverse proportional dependence. The lesser diameter of the focused beam we want to obtain, the greater the

diameter of initial beam we must utilize. The measurements, carried out in the turbulent atmosphere, they showed, that the decrease of the diameter of the focused beam during an increase in the diameter of the initial aperture of source occurs only to a definite limit. After the achievement of this limit, further increase in the diameter of the focused source does not improve its focusing.

Fluctuations of angle of arrival.

The fluctuations of the angle of arrival of the emission/radiation, which passed through turbulent atmosphere, substantially affect the quality of the image, which is formed in the focal plane of optical receiver. When the size/dimensions of random heterogeneities on the way of emission/radiation are be greater the size/dimensions of receiving objective, occurs the displacement of image as whole. Small-scale heterogeneities will mix the separate cell/elements of beam, which leads to "blurring" of image.

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Carried out in the collective of the author experimental study of the fluctuations of the angles of arrival of the emission/radiation of gas laser in wavelength 0.63 μ on the distance of 1.2 μ in atmospheric boundary layer reveal/detect/exposed the

dependence of the dispersion of the fluctuations of angle of arrival on meteorological conditions, diameter of receiving objective and diameter of initial beam. Furthermore, it is reveal/detected that the laser beam can be displaced as whole on several meters with the distance of the propagation of emission/radiation on the order of 10 km for time into tens of minutes and more.

The study of different aspects of the problem of the propagation of laser emission/radiation in the turbulent atmosphere by no means fully it is completed. It is faster, vice versa: are made thus far only first spaces. In particular, are not virtually entirely yet clear the special feature/peculiarities of the fluctuations of the parameters of laser emission/radiation at propagation through the large thicknesses of atmospheric boundary layer, in horizontal directions at different height/altitudes, in inclined directions both from the Earth and from different height/altitudes. Is is weakly studied the effect of the turbulent atmosphere on coherence and polarization of laser emission and series of another questions.

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Chapter Five.

LASER BEAM DISCLOSES NEW PHENOMENA IN THE ATMOSPHERE.

Effect of ray/beam on the atmosphere.

During propagation in the atmosphere giant radiated power, attained in q-spoiled lasers or working in the conditions/mode of the synchronization of modes, are detected completely the new phenomena, connected with the emergence of the so-called nonlinear effects. So, if usual power the given wavelength of emission/radiation is not absorbed by any of atmospheric gases, then at giant power it can be absorbed by any of them. In other cases giant radiated power, on the contrary, leads to the "illumination" of the absorbing atmosphere.

High energy concentration of laser emission causes the emergence of a series of the phenomena, not observed during the propagation of energy of ordinary density. Finally, the new coupling effects of the spread in the atmosphere of laser emission/radiation appear for the short pulse durations, when they become equal or even less than the duration of the event/reports of absorption and scattering of light

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by the molecules of atmospheric gases and the particles of aerosols.

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Common/general/total for these phenomena is that that during their appearance immediately are disrupted the usual laws governing the propagation of optical radiation in the atmosphere, and, first of all, the exponential law of fading monochromatic radiation during its absorption by atmospheric gases and scattering by aerosols. Coefficients of absorption and scattering cease to be the constants of substance, which characterize its absorbing or scattering power. They begin to depend on incident-radiation intensity.

Effect of saturation.

Its essence expresses the dependence of the coefficient of radiation absorption by the molecules of gas on the intensity (power) of the spread emission/radiation. The conducted in the collective of the author rough calculation of power of emission/radiation, which corresponds to the beginning of the manifestation of the effect of saturation in atmospheric gases, gave for the unknown value value on the order of 10^7 W/cm². This power is completely attainable in contemporary lasers; however, thus far are not yet carried out the experimental investigations, which would make it possible to obtain

more precise data. There is no doubt that the threshold values of radiated power for the effect of saturation must depend on the type of gas and on the value of the absorption coefficient of normal conditions.

The dependence of the absorption coefficient on incident-radiation intensity is such, that the greater the radiated power, the lesser the absorption coefficient. Thus, in the conditions/mode of the effect of saturation atmospheric gases absorb radiant energy less than under normal conditions, and begins a peculiar illumination of the atmosphere, an increase in its transparency. Roughly the mechanism of this effect can be explained as follows.

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In proportion to an increase in the radiated power, ever increasing quantity of light quanta from this by wavelength simultaneously falls on an absorbing layer of the molecules of gas, a increasing quantity of molecules of gas, capable of absorbing this emission/radiation, it participates in the process of absorption. Finally can begin such torque/moment, when empty (empty by absorption) molecules will no longer be sufficient.

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Multiphoton processes.

It would seem that during a continuous increase in the radiated power, the atmosphere, "after being saturated" by absorption, will freely pass any addition of power over that, which goes for the maintenance of saturation state. However, upon reaching of the specific power coefficient of emission/radiation, the atmosphere suddenly sharply increases its absorptivity. Further, increase in the power leads to the fact that radiant energy by giant portions jams in the atmosphere, it is more precise, it goes for the excitation of the electronic or vibrational spectra, for dissociation of molecule and ionization of the formed atoms, i. e., energy is expend/consumed on the education/formation of plasma, on the gas breakdown. Most interesting the fact that to absorb begin those gases, which under normal conditions absorb in no way emission/radiation from this by wavelength.

The process of the intense energy absorption of laser emission/radiation by atmospheric gases upon reaching of the specific power is caused by the so-called multiphoton effects of excitation, dissociation and ionization of gases. During multiphoton processes the atoms and the molecules of atmospheric gases simultaneously absorb not one, but several radiation quanta with this frequency (wavelength) so that total energy of these quanta proves to be

sufficiently for exciting of high-energy transitions, or for dissociation and ionization.

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Table 7 given data on the dissociation energy of molecules and ionization of the atoms of atmospheric gases and is shown a quantity of quanta of energy, emitted by lasers on ruby (wavelength 0.69 μ) and on glass with neodymium (wavelength 1.06 μ), of the necessary for dissociation and ionization corresponding atoms and molecules.

The conducted under author's guidance rough calculations of the threshold power of laser emission/radiation, at which begin multiphoton processes in atmospheric gases, gave for this value the value of order 10^{10} W/cm²; Such power are completely attainable in contemporary lasers. Very phenomenon of the breakdown of air by powerful/thick laser momentum/impulse/pulse repeatedly was observed; however, the sufficiently precise quantitative investigations of this interesting phenomenon thus far were not carried out.

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Table 7. Dissociation energy of molecules and ionization of the atoms of atmospheric gases.

(1) Молекула	(2) Энергия диссоциации, эв	(3) Количество квантов, необходимых для диссоциации		(5) Атом	(6) Энергия ионизации, эв	(7) Количество квантов, необходимых для ионизации	
		(4) лазер на 0.69 мк	(4) лазер на 1.06 мк			(4) лазер на 0,69 мк	(4) лазер на 1.06 мк
O_2	5,08	5	3	N	14,5	13	9
N_2	9,76	9	6	O	13.6	12	8
CO_2	2,8	3	2	C	11,27	10	7
H_2O	5,1	5	3	H	13,6	12	8

Key: (1). Molecule. (2). Dissociation energy, eV. (3). Quantity of quanta, necessary for dissociation. (4). laser on...μ(5). Atom. (6). Ionization energy, eV. (7). Quantity of quanta, necessary for ionization.

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Propagation of supershort emission impulse in the atmosphere.

The duration of the pulse of generation can change within extremely wide limits. Meanwhile, the event/reports of absorption and dissipation of luminous energy in the atmosphere continue about nanosecond. Thus, with propagation of the laser pulses of nanosecond and smaller duration in the atmosphere one should expect the special feature/peculiarities of their absorption by the molecules of gases

and the particles of aerosols. In particular, it is possible to arrive at conclusion about the smaller weakening of supershort momentum/impulse/pulses because of the absorption of scattering in the atmosphere. In fact, if one assumes that the pulse duration is smaller than the duration of the event/reports of interaction of world/light with substance, then substance simply will not have time to react to the rapidly jumped emission impulse.

Experimental investigations in this plan/layout are not yet initiated. This is connected with the great difficulties of organizing the investigations. There is no doubt that when they will be overcome, scientists will obtain the possibility to penetrate in the mechanism of interaction of world/light with substance, and who knows perhaps by this method their await new important discovery/openings.

Forced Raman scattering (VKR).

The nature of Raman scattering sharply differs from the nature of molecular, aerosol or turbulent dissipation. The manifestation of Raman scattering it is connected with the presence of optical heterogeneities. The essence of this phenomenon in interaction of the molecules of atmospheric gases with light photons, during which the molecules, together with scattering of the larger part of the

falling/incident on them photons without a change in the emission frequency, into smaller part introduce their inherent frequency changes.

Occurs this as follows. Molecule in the process of interaction with the photon of the specific frequency can scatter it without frequency change, but we can and "add" to photon energy or, on the contrary, "to borrow" from it the energy, equal to quantum energy of its vibrations.

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It is not difficult to see that in this case energy and, therefore, frequency scattered quantum will be than more than or less falling. It is known that each atmospheric gas has its the self-energies of oscillatory quanta and, therefore, its of the frequency of Raman scattering.

It is establish/installed, that during Raman scattering the energy loss on several orders is less than with molecular. Therefore it in the majority of the cases can be disregarded.

The spread in the atmosphere powerful/thick laser emission/radiation can cause the forced Raman scattering on the

molecules of atmospheric gases at such frequencies, such as at usual power are not absorbed.

The effectiveness of this process depends on wavelength or type of atmospheric gas. Detailed data thus far are not acquired. It is known that the forced Raman scattering begins to be exhibited at power, on several orders smaller than by the sample/test of air because of multiphoton processes. This means that VKR - barrier on the path of the propagation of high-power emission/radiation in the atmosphere, which gives about itself to know considerably more earlialy than multiphoton processes.

Self focusing laser emission/radiation in the atmosphere.

During the propagation of high-power laser emission/radiation in the atmosphere, can occur changes of the refractive index of air in the channel of bundle. In this case, the difference in the values of refractive index in the channel of bundle and out of it can be such, with which is removed the divergence of beam. This phenomenon is called self focusing laser emission/radiation.

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As testify calculations, for the elimination of the divergence of

emission/radiation, it is necessary that the difference in refractive indices in channel and out of it is approximately equal to the square of the angle of initial divergence of beam.

To refractive index in the channel of bundle, can affect heating channel, which occurs because of the absorption of laser energy, the effects of Kerr and electrostriction. Kerr's effect consists of the virtually instantaneous orientation of the dipole moments of molecules in the direction of the high electric field as which project/emerges the field of quite laser emission/radiation. Molecules with the oriented dipole moments can be considered as the optical heterogeneity of the medium the refractive index of which depends on the strength of field or on the power of laser emission/radiation. With the effect of electrostriction in the area of action of powerful radiation field, i.e. in the channel of bundle, is created the boost pressure, which gives rise to the appropriate change in the refractive index.

The approximate theory of the phenomenon of self focusing bundle shows that the threshold power of self focusing is proportional to the ability of medium to change its refractive index. The lowest thresholds of self focusing, order several ten kilowatts, possess some liquids. Threshold power for gases compose ten and hundreds of megawatts, i.e. during the propagation of the emission/radiation of

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contemporary lasers in the atmosphere, completely it is possible to expect the manifestation of the effects of self focusing.

During investigations in the atmosphere, is reveal/detected very fact of self focusing powerful/thick laser emission/radiation; however, any in detail it is not studied. In particular, thus far is incomprehensible the nature of the education/formation of the fine/thin filaments of high intensity, which are constant/invariably observed during the propagation of laser emission/radiation within bundle under natural conditions.

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It is possible, these filaments are caused by the effect of the turbulent atmosphere, and we can be, energy concentration, caused by turbulent heterogeneities, contributes to the manifestation of self focusing the individual parts of the bundle.

There is no doubt that the self focusing in real unhomogeneous atmosphere occur/flow/lasts considerably more complex than under laboratory conditions. In any case, it is difficult to itself to present such ideal diagram, when the difference in refractive indices in bundle and out of it on entire course of ray will be exactly of such that to only remove the divergence of emission/radiation. If

this difference in some place will be greater, then this will lead to the focusing of emission/radiation and its subsequent divergence.

It is necessary to hope that in the near future we will know about the phenomenon of self focusing laser emission/radiation in the atmosphere considerably more than we know now. Guarantee to that - important practical value of this phenomenon.

Effect of laser beam on clouds and mist/fogs.

An additional one coupling effect of powerful/thick laser emission/radiation with the atmosphere is connected with the illumination of atmospheric aerosols, first of all clouds and mist/fogs, and mist/fogs, under the influence on them of powerful pulse or continuous emission/radiation. It can be caused by the complete or partial evaporation of particles during their heating because of absorbed energy. It is completely clear, the illumination of atmospheric aerosols strongly must be exhibited for those wavelengths of the emission/radiation to which correspond the maximum values of the absorption coefficient of water (see Fig. 14 on page 90).

Along the data, obtained by the author with colleagues, these wavelengths are arrange/located in spectral intervals with 2.75-3.20;

5.90-6.30 and 10.0-25.0 μ. In the intervals indicated the absorption coefficient is more than 0.05.

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Its maximum value is recorded at wavelengths 17.4; 6.09 and 2.91 μ, where it is equal to with respect 0.563; 0.143 and 0.283. However, far not any of the wavelengths indicated can be effectively used for illuminating of clouds and mist/fogs, if we bear in mind, that the clearing emission/radiation must without large losses pass through atmospheric gases. This means that we must select such intervals of wavelengths, which are not superimposed on absorption bands, and then among those selected to find the narrow atmospheric windows, free from the lines of absorption.

Is most promising for illuminating of clouds and mist/fogs the range of wavelengths from 10 to 12.5 μ. It coincides with the center of the long-wave atmospheric window, since the regions of the spectrum 2.75-3.20; 5.90-6.30 and 12.5-25 μ are occupied with the absorption bands of atmospheric gases. Specifically, into area from 10 to 12.5 μ, falls the emission/radiation of most powerful gas laser on the mixture of carbon dioxide with nitrogen (wavelength 10.6 μ). The absorption coefficient of liquid water for this wavelength is equal to 0.07; True, for a wavelength 12.5 μ it already reaches

values by 0.25; however, to this wavelength thus far is not created sufficiently powerful/thick laser.

Under the influence of powerful/thick emission/radiation on the particles of clouds and mist/fogs on the transparency of medium, they affect: the complete or partial evaporation of droplets, directed the particle motion, caused, on one hand, by light pressure, on the other hand - nonuniform heating during pulsed effect; the explosion of particles, if absorbed energy it is sufficient so that in their center the temperature would achieve critical. The effects indicated are investigated in detail both theoretical and experimental in the collective of the author.

The dominant role among the effects, which affect the illumination of medium, plays evaporation. The mechanisms of evaporation are different for the continuous and pulse emission/radiation of different duration.

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Let us give some examples of the results of the calculations, instituted on the use of the developed theory. Figure 26 depicts the dependence of a radius of water spherical particle on time under the continuous influence on it of emission/radiation in wavelength 10.6 μ

by power 10^2, 10^3 and 10^4 W/cm². The initial diameter of drop in all cases is equal to 30 μ. As can be seen from figure, the particle with a radius of 30 μ, into 4-6 times exceeding the most probable radius of the particles of the most frequently encountered clouds, almost completely it evaporates during several hundredth or thousandths of a second.

Figure 27 depicts the results of the calculations of the terminal radius of particle depending on initial under the single pulse radiation effect in wavelength 10.6 μ. Curves correspond to the values of the pulse energy, equal to 2.00; 2.66 and 2.93 kJ/cm².

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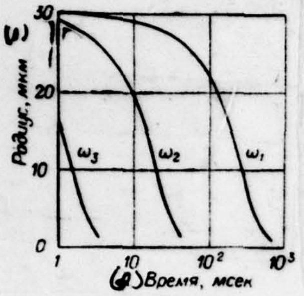

Fig. 26.

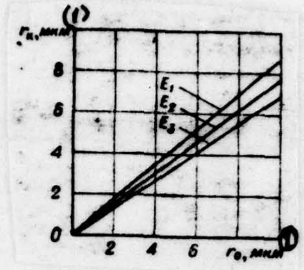

Fig. 27.

Fig. 26. Results of calculation of change in radius of drop in the course of time of its continuous irradiation by flow in wavelength 10.6 μ and power $\omega_1=10^2$ W/cm², $\omega_2=10^3$ W/cm², $\omega_3=10^4$ W/cm². Initial drop radius $r_0=30$ μ.

Key: (1). radius, μm. (2). Time, ms.

Fig. 27. Results of calculation of terminal radius of drop depending on initial radius at values of pulse energy $E_1=2.00\cdot10^3$ J/cm²; $E_2=2.66\cdot10^3$ J/cm²; $E_3=2.93\cdot10^3$ J/cm².

Key: (1). μm.

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As show investigations, under the influence of the separate

momentum/impulse/pulses the radius of particle changes insignificantly, if absorbed energy heats it not more than on 130°C. Heating to temperature is higher than 375°C (critical temperature higher than which water we can be located only in gaseous state) is not sense to examine. Thus, are of interest only those effects of the action of the single momentum/impulse/pulses by which the temperature of drop is raised to the value, included in range from 130 to 375°C.

From theory it follows that under the pulse influence a radius of drop can become the equal to 0 only at critical temperature, if the pulse duration is less than 10^{-4} s. If absorbed energy it is sufficient so that the temperature of particle would rise to critical, then one should expect the explosion during which by the water vapor at a large pressure it is hit against air and is formed compression wave. Calculations show that at a distance from particle, the approximately equal to 10 to its radii, the products of explosion completely give up their energy to air. The time of the dispersion/divergence of the products of explosion for the water drops with a radius of 10 μ is equal to millisecond.

The experimental studies of the effect of continuous and pulse emission/radiation on single particles and on water artificial mist/fog confirmed the mechanisms of the evaporation of water particles, forecasted by theory. Were for the first time

reveal/detected the explosions of particles under the pulse influence and the established fact of the partial illumination of water mist/fog under pulsed and continuous influence. It turned out that the degree of illumination does not depend on particle concentration, but illumination itself under the continuous influence is spread with the definite speed which depends on the wavelength, power density of emission/radiation and the microstructural parameters of cloud or mist/fog.

The problem of the formation of the clear channel far is not solved.

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Even if it seems that developed of particles is valid for any power coefficients of the affecting emission/radiation (for this still it will be necessary to supply very complex experiments with powerful/thick radiation sources), then this it will only mean that we will be able to forecast expenditures of energy on channeling in the hypothetical case of the clouds or mist/fog whose particles are motionless. In the real cloud of particle, they are found in intense motion caused by wind and gustiness. Thus, the clear channel will continuously wash off itself. Furthermore, thus far not it is clear, as will bring themselves vaporization products. It is possible also

to expect that optical properties of channel they will be unusual as a result of the emergent temperature heterogeneity.

The formation of the clear channel in clouds and mist/fogs has so enormous applied a value, that within the next few years we, undoubtedly we learn about the channel itself, its parameters and diverse properties incomparably more than we know now.

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Chapter Six.

LASER BEAM PROBES THE ATMOSPHERE.

From the point of author's view, widest application the lasers find precisely during the remote sensing of the atmosphere.

It is first of all necessary to explain value and potential advantages of the method of the remote determination of different atmospheric parameters. The knowledge of the atmospheric parameters is important for many directions of science and technology. To astronomers and geodesists it is necessary for "cleaning of" the results of its observations from the undesirable effect of the atmosphere. Astrophysicists the knowledge of atmospheric processes helps to check hypotheses and theories, which explain physical processes in the atmosphere other celestial bodies. To the creators of the diverse new technology, intended for the mastered optical wavelength range, the quantitative data on the atmospheric parameters are necessary in order to previously rate/estimate the effect of the atmosphere on the effectiveness of the developed/processed means, on their practical use. But the greatest need in the enormous array of

the quantitative data on the atmospheric parameters constantly experience/test meteorologists, occupied with solution of one of humanity's most important problems - with weather forecasting.

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Now hardly will be located on our planet although one sober-minded person, which did not agitate the practical side of this large problem. And although the authenticity of weather forecasts, in particular short term ones, with each year is raised, nevertheless no one will fail for itself courage to say that it will be finally solved into the nearest 10-15 years.

Thus, on agenda will cost the urgent task of the development of the completely new methods of the study of the atmospheres which would ensure the solution of the problem of the operational collection of a considerable quantity of precise data on all important atmospheric parameters. Such requirements satisfy the methods of the remote sensing of the atmosphere with the use of electromagnetic or acoustic waves. Important place among them belongs to the laser sounding of the atmosphere.

The remote sensing of the atmosphere with the aid of lasers has the enormous potential possibilities which are connected with the

possibility of using all without the exception/elimination of the surprising properties of the emission/radiation of laser sources for the extraction of information about different atmospheric parameters. The method of the laser sounding of the atmosphere has a series of indisputable advantages, which open/disclose the tempting prospects for its practical use.

The uncommonly short duration of the sounding emission impulse automatically provides fantastically high spatial resolution of the obtained information. Relatively simply is reached the pulse duration into 10 nanoseconds at power into hundred megawatt, which causes spatial resolution, measured in all by several meters (momentum/impulse/pulse of this duration at the speed of propagation 300,000 km/s occupies the path in all 3 m; therefore, at each given torque/moment the atmosphere sends response for the passing through it emission/radiation only from section 1.5 m).

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The large power of laser pulse determines its propagation up to enormous distances in the atmosphere. In the area of receiving mirror of approximately 1 m^2, the momentum/impulse/pulse with a power of into hundred megawatt for duration into 10-30 nanoseconds is capable to give the echo from the aerosol layers of the cloudless atmosphere

continuous signal in vertical direction to the height/altitudes of 30-50 km. From this signal in principle, it is possible to extract information about continuous profile of the corresponding meteorological element.

But,if we utilize not one, but the pulse train of emission/radiation, then the ceiling of sounding can be led to the height/altitude, equal to 100 km and it is more.

Contemporary lasers make it possible to obtain tens of powerful/thick momentum/impulse/pulses per second. This means that with their aid it is possible to investigate the dynamics of the diverse rapidly elapsing atmospheric processes.

Information about the airfoil/profiles of meteorological elements or their discrete values in any, preassigned small localized volume, virtually can be obtained instantly, if the receiver of laser locator is connected with high-speed electronic computer and, it goes without saying, if will be developed the mathematical algorithms of the unique solution of the corresponding task.

Especially tempting prospects are open/disclosed during the laser sounding of the atmosphere from near Kosmos. Calculations show that if the sounding is carried out from the height/altitude of 300

km, then with the aid of one momentum/impulse/pulse it is possible to obtain information about continuous the airfoil/profiles of the echo signal, beginning with the height/altitudes of 100-150 km, up to the surface of the Earth. For this, it is sufficient so that for the pulse duration in several ten nanoseconds its power would be equal by several to hundred megawatt, and the diameter of receiving mirror ≈0.5 m.

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Essential advantage of sounding the atmosphere from Kosmos - possibility of the operational collection of necessary information on planetary scale.

Finally, several words about the cost/value of the laser sounding of the atmosphere. During the development of any new method, this question has far last/latter value. We can seem that the echo method of the atmosphere with the aid of lasers fails economic competition with the widespread method of radiosonde observation. Real/actually, while unique laser locator will cost several times more expensive than equipment, intended for a standard radiosonde observation. But, in the first place, this equipment have long discharged in series, which considerably decreases its cost/value, in the second place, each launching/starting of radiosonde requires expenditures, many

times exceeding the cost/value not of one, but the whole series of laser pulses. It is possible nct tc doubt that the method of the laser scunding of the atmosphere will prove to be considerably more economical than the radiosonde observation and, all the more, aircraft and rocket sounding.

Basic ideas and of the diagram of their application/use.

The propagation of pulse or continuous laser emission/radiation in the atmosphere is always accompanied by its scattering in different directions in accordance with the indicatrices of molecular and aerosol scattering. In principle it is possible to accept the emission/radiation, scattered at any angle. However, in practice widest use found the systems of the combined source and receiver (Fig. 28). In such systems one and the same mirror form/shapes the radiant flux of laser, and is accepted back-scattered echo signal. As we see, in this case, necessary in no way to worry about coincidence or intersection of the optical axes of source and receiver, this occurs automatically. Certain modification of this system are laser locators, whose source and receiver are spread up to small distance, on the order of 0.5-1 m (Fig. 29).

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The optical axes of source and receiver in this case can intersect at different distance from locator. Both with those combined the source and the receiver and with the small distance between them for sounding the atmosphere can be used only pulse emission/radiation: if source sends to the atmosphere continuous emission/radiation, then into receiver it will simultaneously enter the reflected from different layers emission/radiation, and its interpretation - too thankless a task.

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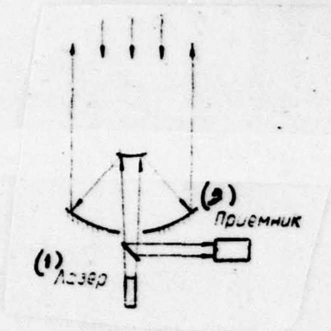

Fig. 28.

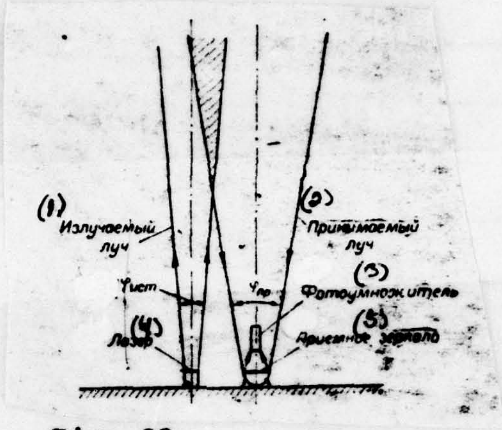

Fig. 29.

Fig. 28. Diagrammatic representation of system of combined source and receiver, most widely used during laser scurding atmosphere.

Key: (1). Laser. (2). Receiver.

Fig. 29. Diagram of laser lccator, when source and receiver are arrange/located together.

Key: (1). Emitted. (2). Received. (3). Fhotcmultiplier. (4). Laser. (5). Receiving mirrcr.

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The second diagram of the laser scundirg cf the atmosphere,

presented in Fig. 30, was called the diagram of bistatic sounding. Its characteristic feature, the large basis between the source and the receiver,. In this diagram, on the contrary, to more preferably utilize lasers with continuous emission/radiation. The optical axes of source and radiation detector can intersect, generally speaking, at different height/altitudes. If we fix the height/altitude of intersection, then receiver it will obtain information in the form of the scattered at the specific angle world/light from one and the same localized volume, therefore, it is possible it is continuous to follow the dynamics of atmospheric processes in the selected volume.

But, if us interest the atmospheric parameters, which relatively slowly change in time, then a bistatic diagram can be utilized for the investigation of the elevation profile of one or the other parameter. In this case, during the continuous rotation of the optical axis of receiver (source) it is possible at will to change the height/altitude of sounding - necessary only to follow, that the optical axes of source and receiver constantly intersected.

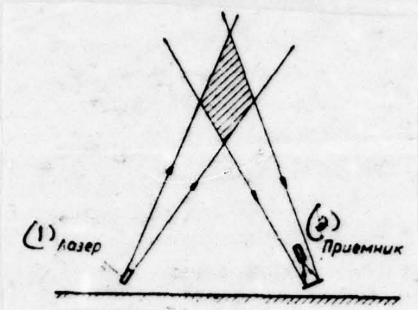

Fig. 30. Diagrammatic representation of the bistatic laser sounding of the atmosphere.

Key: (1). Laser. (2). Receiver.

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Bistatic sounding of the atmosphere gives the possibility of intensity measurement of that scattered at different angles of radiation (part of the indicatrix of scattering). This possibility is important for developing the algorithms of the extraction of single-valued information from the results of sounding. Bistatic diagram was adopted in last 1-2 years.

Let us finally examine an additional one possible geometric diagram of the arrangement/position of source and receiver during the laser sounding of the atmosphere. It assumes the use of information about the atmosphere, which bears on itself scattered forward

radiation. Its realization can be realized in two versions (Fig. 31 and 32). With the first version the optical axes of source and receiver coincide or almost coincide, but they are directed to opposite sides (receiver looks towards source).

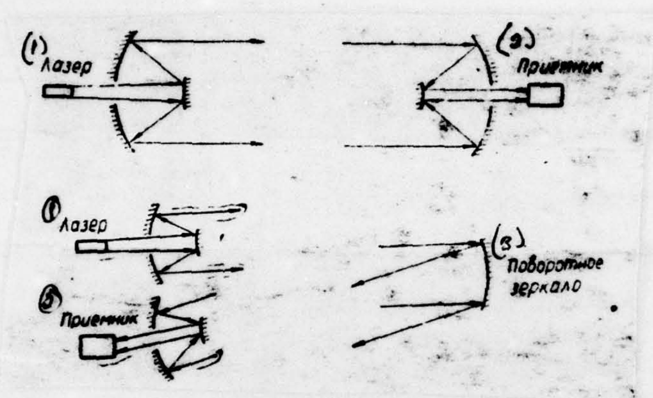

Fig. 31, 32. The versions of the geometric diagram of the laser sounding of the atmosphere:

1) the optical axes of source and receiver either they coincide or almost they coincide, but they are directed to opposite sides;

2) receiver is placed not far from source. Receiver records scattered forward radiation, occurring during pulse propagation from source to rotary mirror, and from it - to receiver.

Key: (1). Laser. (2). Receiver. (3). Rotary mirror.

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With the second version the receiver is placed not far from source and records scattered forward radiation which appears during pulse propagation from source to rotary mirror and from it - to receiver. The distance between the source and the receiver is determined by the size/dimensions of direct/straight beam after its dual passage in the layer between the source and the mirror. In principle, here can be used the diagram of the combined method, if the optical axis of rotary mirror is turned to the small angle of the relatively optical axis of source.

The described diagram is instituted on pulse emission/radiation. Its advantages are determined by considerably larger sensitivity during recording of that scattered by the particles of the aerosol of world/light. The intensity of scattered on atmospheric aerosols radiation in the direction forward on several orders is more than in the direction back/ago. This means that during sounding of the atmosphere can be reached the respectively larger distance. An essential deficiency/lack in this system in the fact that source and receiver must be placed on opposite ends of the probed route: in one

end/lead to establish/install source and receiver, but in other - rotary mirror. Apparently, most it is simple to realize this diagram during sounding of atmospheric boundary layer or during inclined sounding in mountains. But here the high sensitivity of method not too is necessary. In each the cases are obtained sufficiently large echo signals during backscattering. Therefore most prospects but, probably, the application/use of the examined diagram on the routes between the Earth and its artificial satellite or orbiting space station.

All the examined above geometric diagrams of the laser sounding of the atmosphere are used for recording not only aerosol and molecular, but also Raman and resonance scattering, although in the last/latter two cases we are dealing with other mechanisms of scattering.

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During Raman scattering we are dealing with scattering by the molecules of one or the other atmospheric gas of the frequencies, different from the emission frequency of the exciting laser pulse. The intensity of this scattering on several orders is less than molecular one, but it occurs at another frequency and therefore we can be clearly recorded.

Resonance scattering is connected with the absorption of the emission frequency of laser pulse by the molecules of any atmospheric gas with the subsequent re-emission this same of frequency. In other words, laser pulse with the appropriate resonance emission frequency, passing through the atmosphere, leaves after itself the glowing loop of atoms or molecules, recording the intensity of which can give to us information about gas concentration at different height/altitudes. Specifically, thus recorded vapors of sodium in upper atmosphere. Resonance scattering possesses considerably larger intensity, than all other forms of scattering; therefore with its aid, in principle, it is possible to obtain the data on the very small concentrations of a series of atmospheric gases. But for this it is necessary to have lasers with previously known resonance for this gas emission frequency. Such lasers have already been created.

Equipment/device of laser locator (lidar).

All the laser locators, intended for sounding the atmosphere, have the following basic cell/elements: 1) laser; 2) the collimating system; 3) rotary equipment/device; 4) receiving optical system; 5) radiation detector with the system of filters and amplifier; 6) the monitor of emission/radiation.

Let us examine each of the cell/elements separately.

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Requirements for the parameters of the lasers, suitable for sounding the atmosphere, depend on the character of problem. Widest use obtained ruby generator at wavelength 0.6943 μ with the duration of pulse 10-30 ns at power several ten megawatt. The divergence of beam of emission/radiation on leaving from generator is equal to several angular minutes. The pulse repetition frequency is low. As a rule, it does not exceed several pulses per minute. Besides laser on ruby, are utilized solid-body generators on glass with neodymium (wavelength of emission/radiation 1.06 μ), on the second harmonics of the emission/radiation of ruby laser (wavelength 0.3472 μ) and of laser on glass (wavelength 0.53 μ), and also lasers from the reconstructed by a wavelength on dye/pigment (wavelength in the visible region of the spectrum 0.5896 μ), gas lasers on nitrogen (wavelength 0.3371 μ) and on ionized argon (wavelength from 0.48 to 0.52 μ).

The collimating system simultaneously increases the diameter of exit beam and decreases its divergence. It is the system of mirrors

cr lenses. The diameter of exit beam is centimeters - tens of centimeters. With the combined method large collimator mirror performs the role of receiving antenna. Its diameter estimates distance of the action of locator. In some of such systems, the diameter of receiving mirror reaches 1.5 m.

Rotary equipment/device provides the rotation of the optical axis of locator, which is necessary for sounding the atmosphere in any direction.

Receiving optical system, in principle, in no way differs from the collimating system. During sounding of the atmosphere at high altitudes, the size/dimensions of receiving antenna have important value. In Kingston, Jamaica, is created the installation in which reflected as upper air the echo signal of laser pulse is simultaneously received to the system of mirrors with total effective area of the equal to 16 m².

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Radiation detectors usually serve the photomultipliers. For an increase in sensitivity and operational stability, sometimes is applied their dry cooling. The photomultiplier is placed in the focus of receiving optical system. Before its input window are

establish/installed different filters.

The interference light filter, employee for decreasing the interferences of atmospheric origin, usually has a passband on the order of 20 Å. The use of more narrow-band filters will lead to the considerable decrease of interferences. Calculations showed that with filters in width to 1 Å sounding of the atmosphere to high altitudes can be it will be carried out at any time of days.

Recorder fulfills the functions of amplification and measurement of that taken by the photomultiplier of signal. Recording the echo signal reflected is conducted by photography from oscilloscope face or on magnetic tape.

EQUATION OF LASER LOCATION.

For the lower 30-kilometer layer of the atmosphere, if information from it is obtained with the message of one emission impulses, the equation of laser location is analogous with the equation of radar. For a laser pulse with small divergence, when nonlinear effects and effects of multiple scattering can be disregarded, the power of the echo signal, accepted from scattering volume from height/altitude h, it is proportional to the power of initial momentum/impulse/pulse, its duration, area of receiving

mirror, to the square of the transparency of the layer of the atmosphere from locator to scattering volume, to volumetric back-scatter factor and it is inversely proportional to the square of distance to scattering volume.

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As we see, into the equation of location, enter two unknown values: the transparency of the layer of the atmosphere between the locator and the scattering volume and volumetric back-scatter factor. Completely it is clear that from the recording of the echo signal reflected we cannot obtain immediately both unknown values. Therefore for the interpretation of information one of the values must be known to previously or measure separately in order to obtain the data on the second. Let us consider that to us is known the transparency of the layer of the atmosphere on the course of laser pulse, determined in this or some other way (it, for example, it is possible to determine by the same laser locator, after probing the atmosphere at different angles).

Let us try now to be dismantle/selected, what useful information we can extract from the obtained airfoil/profile of volumetric coefficient of scattering.

Let us first of all emphasize that into the obtained airfoil/profile simultaneously are introduced the contribution and the aerosol, and molecular scattering, without separation of which we will move not to the space in the interpretation of the obtained results. Separation usually carries out, on the basis of the assumption that the volumetric coefficients of molecular scattering are known, then it is not difficult to obtain the appropriate volumetric coefficients of reverse aerosol scattering. But they by themselves do not represent great practical interest. For practice it is important to know: the concentration of particles, according to sizes, form and chemical composition or, at least, volumetric coefficient of scattering. Unfortunately, not one of the values indicated cannot be extracted from the data on volumetric back-scatter factor.

If in molecular scattering there is single-valued communication/connection between the coefficient of scattering and the back-scatter factor (molecular scattering has only one indicatrix of scattering), then in aerosol scattering there is no this single-valued communication/connection.

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Therefore in order from the data of sounding to extract information

on concentration of particles or volumetric coefficient of scattering (about other parameters of aerosols thus far early to speak), it is necessary to utilize new assumptions. So, if the particles of aerosol are are considered spherical with known refractive index and are assigned their spectrum of size/dimensions, then of the data on the volumetric coefficients of reverse aerosol scattering it is possible to obtain particle concentration, and volumetric coefficient of scattering. It is not difficult to see that the values of these values depend on how correctly reflect the assigned parameters real picture.

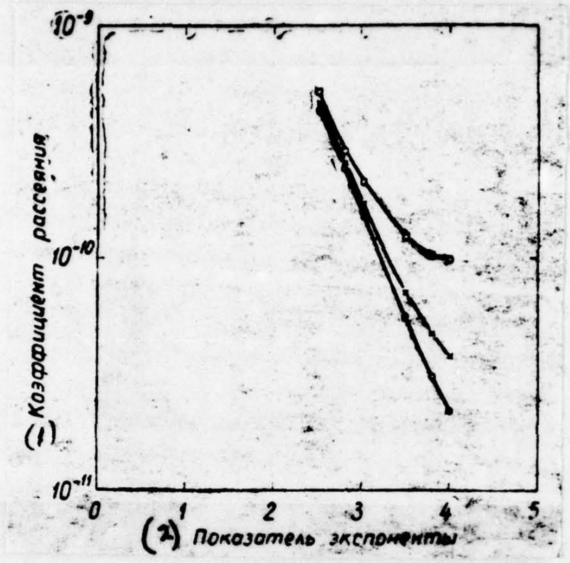

Fig. 33. Results of the calculations of the volumetric back-scatter factors for the different values index of the exponential function, which describes the spectrum of particle sizes, and different particle concentrations.

Key: (1). Coefficient of scattering. (2). Index of exponential.

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In order to emphasize the possible ambiguity of the described diagram of the interpretation of the sounding data, we give the results of the calculations of the volumetric coefficients of backscattering for the different values index of the exponential function, which

describes the spectrum of sizes of particles and of different concentrations of particles (Figs. 33-34). The range of changes in these parameters is selected so as to overlap their values in real atmosphere.

From figures it is evident that the value of the echo signal of laser pulse reflected can several times change during a change in the microstructural parameters of the particles of the aerosols. This fact demonstrates the complexity of the problem of the single-valued extraction of information about the characteristics of aerosol education/formation. Let us note also that the intensity of backscattering by particles is very sensitive to a change in the index of their refraction. It can considerably vary during a change of the refractive index in interval from 1.33 to 1.50. Let us recall that for the visible region of the spectrum value of 1.33 has liquid water, and value 1.50 is accepted to assign to solid aerosol particles.

The described diagram of the laser sounding of atmospheric aerosols far is not ideal and does not provide single-valued information even when is previously known a precise value of molecular scattering. Therefore are necessary the searches of the new diagrams which either utilized in no way a priori information about the atmosphere, or they would bring together it to the minimum. In

particular, there is great interest in the single-valued separation of scattering into aerosol and molecular.

The basic ideas of the new diagrams of the laser sounding of atmospheric aerosols whose introduction can substantially move the problem of the uniqueness of extracted information consists of the following. First of all, this is - multifrequency sounding, instituted on different dependence of the coefficients of aerosol and molecular scattering on wavelength, which, in principle, provides the possibility of the unique solution of problem during measurements with a sufficient number of wavelengths.

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A quantity of wavelengths depends substantially on that, will be utilized any a priori information about the model of atmosphere dispersion.

Use of a phenomenon of Raman scattering will make possible of the independent determination of the echo signals, caused only by molecular scattering.

In the bistatic diagram of sounding, the information about the microstructural parameters of atmospheric aerosol can be obtained

during the measurement of the emission/radiation, scattered at different angles at one and the same height/altitude. This is achieved by the appropriate displacement of the intersection of the optical axes of locator and receiver. If one assumes that the atmosphere is uniform in horizontal direction, during the consecutive use of the given diagram it is possible to obtain the elevation profile of the unknown microphysical characteristics. Supplementary information about the parameters of atmospheric aerosols during their laser sounding will give measurement of the polarizational characteristics back-scattered emission/radiation. Finally, recording the strain of the emission impulse reflected, which depends on the concentration and the spectra of particle sizes, also can be used for the interpretation of the results of laser sounding.

With laser sounding of upper air, the echo signal is so it is weak that into receiver fall only the separate photons.

Therefore reliable registration of the signal is possible only with the statistical accumulation of reflected off the specific layers of the atmosphere of photons with a sufficiently large quantity of sent in the atmosphere laser pulses.

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SOUNDING THE AEROSOLS OF THE TROPOSPHERE AND OF THE STRATOSPHERE.

In this section we will examine the results of sounding the tropospheric and stratosphere aerosols which are obtained in work with single emission impulses. The ceiling of this sounding for sufficiently powerful/thick locators is equal to approximately 30-50 km.

On Fig. 35, are given the dependences of the ratios of the measured volumetric back-scatter factors to calculated ones for molecular scattering on the height/altitude of sounding. We see that in all cases clearly is detected the wide aerosol layer with maximum approximately 20 km. This layer was reveal/detected Young during the direct measurements of the concentration of the optically active particles of the atmospheric aerosol and with optical measurements from Soviet spacecraft.

Knowing the spectrum of particle sizes, their refractive index, when the particles have spherical form, from the data given in the figure, we can extract information about the altitude path of particle concentration and of the volumetric coefficient of aerosol scattering.

During sounding of the atmosphere by single and single-frequency

momentum/impulse/pulse it is possible to investigate: the stratification of the layers of invisible ones by eye, but the optically active particles of the aerosol or the course of laser beam (number of layers, their extent, relative density, fine structure); the three-dimensional/space structure of the field of the particles of the same aerosols during sounding in different directions; the dynamics of the stratification of aerosol layers and their three-dimensional/space structure; the contamination of atmospheric boundary layer (space-time characteristics) by the departure/withdrawals of the industrial activity of man; the transparency of the atmosphere in horizontal and inclined directions, and to also determine lower boundary and some other parameters of clouds.

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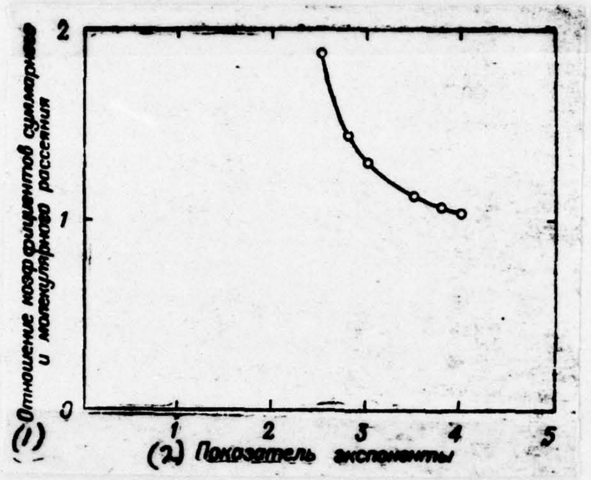

Fig. 34. Results of the calculations of the ratio of total volumetric back-scatter factor to the volumetric coefficient of molecular scattering of the different values of the index of the exponential in formula Young.

Key: (1). Ratio of the coefficients of total and molecular. (2). Index of exponential.

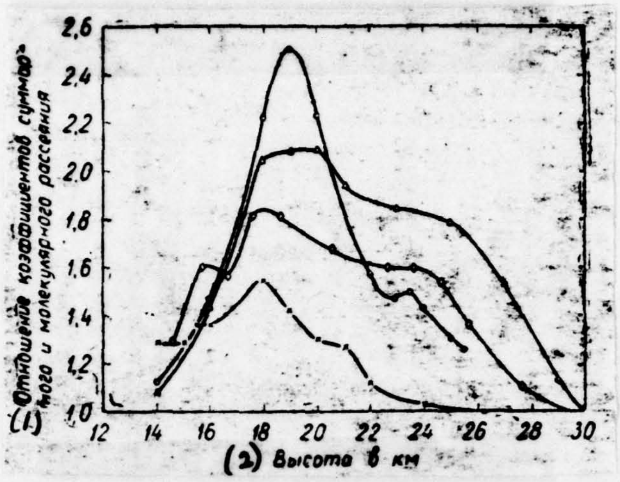

Fig. 35. Dependences of the ratio of volumetric back-scatter factors to calculated ones for molecular scattering on the height/altitude of sounding according to different authors.

Key: (1). Ratio of the coefficients of total and molecular scattering. (2). Height/altitude km.

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It is possible to expect that the stratification of aerosol layers is connected with other meteorological parameters. In any case, already there are the data about the fact that the aerosol layers are usually connected with temperature inversions. This open/discloses an additional one possible way of applying the

single-impulse sounding. Finally, in proportion to the accumulation of the experimental data on the spectra of size/dimensions and refractive indices of the particles of the aerosols ever more and more will grow/rise the uniqueness of the data on concentration of particles and volumetric coefficients of scattering, extracted from sounding by single momentum/impulse/pulses.

Apparently, still faster will be improved the diagrams of laser sounding.

At the 3rd conference on the laser sounding of the atmosphere, which was taking place in Kingston valve on jamaica during September 1970, it was described the diagram, instituted on the bistatic laser sounding of the atmosphere, during which is measured the intensity of the emission/radiation, scattered at different angles at one height/altitude. It was assumed that the atmosphere was uniform in horizontal directions. The position of the optical axes of locator and receiver is changed so that the point of their intersection remained at one height/altitude, and angles changed.

Processing measurable data carried out as follows. Was taken model with the assigned spectrum of particle sizes and their refractive index (particles are considered spherical) and was calculated the probable intensity of that scattered at different

angles of radiation. The results of calculation and experiment compared. Model with the method of successive approximation is changed, thus far were not obtained conformity between calculated and experimental data.

With the aid of the described method they explained that at the height/altitudes of more than 20 km predominate the particles of small size/dimensions (0.2-0.3 μ on a radius) the refractive indices of which change from one case to the next.

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At the same time were detected the mixtures of particles with different refractive indices.

At the 4th conference on the laser sourding of the atmosphere, which passed at the end of January of 1972 in the USA (Tuscon, Arizona), was represented the whole series of reports at least from five different groups, attempting to develop the method of the extraction of information about the concentration and the spectra of the sizes of the particles of the aerosols from the results of laser sounding. One of the reports prepared the institute of optics of the atmosphere of SB AN USSR [Siberian Branch of the Academy of Sciences of the USSR].

DETERMINATION OF THE TRANSPARENCY OF THE ATMOSPHERE.

One of the methods of determining the transparency of the atmosphere in vertical or inclined direction is instituted on use for sounding the atmosphere of laser locator. The essence of method consists of following. If we measure the intensity of the scattered from one and the same height/altitude signal during sounding of the atmosphere at different angles, then it is possible on slope/inclination by straight line, constructed according to the results of measurements in the specific coordinates, to determine at base altitude the transparency of the layer between the locator and the volume being investigated. Since during sounding by one momentum/impulse/pulse we obtain the smooth curve of the values of the intensity of backscattering from different height/altitudes, then with the aid of this method it is possible to obtain the data on the transparency of any layer and, therefore, to study the process of changing the transparency with height/altitude.

Those constructed according to the results of the measurements of curve/graph must give straight lines, if the atmosphere is uniform in horizontal direction, i.e., when coefficients of aerosol and molecular scattering remain constants in horizontal planes over the

area of sounding. If this condition is not satisfied, then of straight-lines relationship it will not be obtained, that it will automatically mean that for determining the transparency of the atmosphere the method is unacceptable.

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Consequently, this method can be used for the check of the horizontal uniformity of the atmosphere. The coordinates in which one should construct curve/graphs, are obtained directly from the equation of laser location for the case of the inclined sounding of the atmosphere.

The described method was successfully used in practice.

In several reports at the 4th conference on the laser sounding of the atmosphere, they proposed an additional one method of measuring the transparency of the atmosphere with the aid of lidar. Its essence consists in following. If we measure the echo signal of laser pulse at the frequency of Raman scattering of nitrogen, then, taking into account the constancy of the concentration of the latter and knowing scattering cross sections, is not difficult to determine the transparency of the layer of the atmosphere, comparing the measured echo signals with their values, designed for the pure/clean atmosphere.

SOUNDING THE AEROSOLS OF MESOSPHERE.

The data of the laser sounding of mesospheric aerosols are very contradictory. So, in the experiments, carried out in different time in England, in Alaska, in Sweden, Norway, near Washington in the USA at height/altitudes of approximately 70 km, echo signal exceeded computed value, obtained upon consideration only of molecular scattering, from several ten to several hundred percent. The results of measurements on jamaica were in complete agreement with the data of the calculations, carried out only on the basis the account of molecular scattering of light.

In the overwhelming majority of investigations, the aerosols at height/altitudes from 30 to 60 km are not reveal/detected.

Investigations of aerosols in mesosphere, carried out by twilight method, method of searchlight sounding and during the launching of rockets, it also gave the contradictory picture which, possibly, is explained by the fact that the measurements carried out in different time and in different places.

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However, if we summarize all data, then during their comparison with the results of laser sounding appears one common/general/total nonconformity. It lies in the fact that all other methods detect aerosols at all height/altitudes in mesosphere, including at height/altitudes from 30 to 60 km. The numerical values of coefficients of aerosol scattering in area of the green section of the visible region of the spectrum oscillate within considerable limits. In some data, the coefficient of aerosol scattering several times was above the coefficient of molecular scattering in all interval of the height/altitudes of mesosphere.

Thus, between the data of the studies of aerosols in mesosphere, obtained during the laser sounding of the atmosphere and with the aid of other methods, exist the disagreements whose true reason to establish/install thus far is difficult. Completely, however, it is possible that these disagreements seeming and simply reflect the diversity of the aerosol structure of mesosphere and its dependence on place and time. One of the obvious cell/elements of this diversity - noctilucent clouds, which appear only in the completely specific months and at large latitudes.

It is establish/installed, for example, that the concentration

of aerosol particles in noctilucent clouds can by 3 orders exceed its value in the absence of clouds. The spectra of the size/dimensions of these clouds are described by formula Young with exponent 4 and 5 with the sharp break of curve in the minimal sizes of particles with a radius of 0.02 μ; therefore the appearance of clouds sharply changes the coefficients of aerosol weakening at the appropriate height/altitudes (83±4 km, on last/latter data). Let us emphasize that the laser sounding, carried out in Sweden and in Alaska in the summer of 1964 and in Norway in the summer of 1966, made it possible according to the echo signal reflected to measure the extent and to rate/estimate the optical thickness of noctilucent cloud.

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It is interesting to note that the maximum of the echo signal reflected in this case fell on height/altitude of approximately 70 km, i.e., approximately 10 km lower than medium altitude of noctilucent clouds.

The second important factor, which substantially affects the concentration of particles of the aerosols in mesosphere, micrometeor dust whose content changes in time and space. Was recently expressed an additional one hypothesis about the possible reason for the variability of aerosols in the atmosphere, including in mesosphere.

According to this hypothesis, the dust from the comets whose orbits pass through the Earth's atmosphere, can during the specific period be located in upper atmosphere. This invisible by eye dust upon entry into the atmosphere is destroyed to particles with size/dimension about 1 μ on a radius, which then gradually deposit down.

A question concerning the authenticity of the data on the mesospheric aerosols, obtained during laser sounding, finally can be solved only if succeeds in sufficiently accurately dividing the measured echo signals into components, obliceds molecular and aerosol scattering. In fact, if to height/altitudes into 30-40 km atmospheric density and, consequently, also molecular scattering they change unessentially, then at the high altitudes of a variation in the atmospheric density sufficiently larage. It is completely clear that in this case is difficult to rely on the reliable results of laser sounding, if they are instituted on the calculations of the a priori portion of the echo signal, caused by molecular scattering.

One of the possible versions of the separate definition of echo signals, caused by aerosol and molecular scattering, consists of the following. Since the coefficients of molecular and aerosol scattering they have different dependence on the wavelength of the emission/radiation (the first is inversely proportional to the fourth, and the second - approximately the first degree of

wavelength), then is not difficult to find such wavelengths of the emission/radiations during which it is possible to disregard one form of scattering.

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For this, are required the lasers with the appropriate wavelengths with the adequate/approaching parameters (is first of all important pulse power, pulse duration and their recurrence).

Analysis shows that the necessary requirements they can satisfy the following lasers: generator on fluorite with dysprosium (wavelength of emission/radiation 2.36 μ); generator on the second harmonic of ruby laser (wavelength of emission/radiation 0.3472 μ) and gas laser on nitrogen (wavelength 0.3371 μ). Let us give the data on the coefficients of aerosol and molecular scattering for firstly of these wavelengths. In the atmospheric boundary layer, turbid by particles with the most probable values of the parameters of microstructure, at visibility 10 km the coefficients of aerosol and molecular scattering are respectively equal to $7 \cdot 10^{-2}$ and $6 \cdot 10^{-5}$ km^{-1}, i.e., they differ from each other approximately 1000 times.

Entire layer of the atmosphere attenuate/weakens the emission/radiation in wavelength 2.36 μ because of the molecular

scattering in all approximately by 0.03o/o, which cannot be recorded by the best contemporary instruments during measurements in real atmosphere. Consequently, after probing the atmosphere by laser on fluorite with dysprosium, it is possible to disregard the contribution to echo signal because of molecular scattering. In other words, virtually we will measure the pure/clean aerosol echo signals. The value of these signals must be approximately of the same order as as during sounding by laser on ruby, although the coefficient of aerosol scattering for a wavelength 2.36 μ several times is less than for emit/radiating the generator on ruby. This is explained by the fact that for a wavelength 2.36 μ the coefficient of asymmetry of indicatrix of scattering less and volumetric back-scatter factor proves to be respectively more.

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The coefficient of molecular scattering for a wavelength 0.3371 μ 27 times more than for a laser on ruby, while the corresponding difference in coefficients of aerosol scattering is approximately equal to 2. Thus, after probing the atmosphere by generator on molecular nitrogen, we obtain the echo signals, mainly caused by molecular scattering.

Generator on fluorite with the dysprosium, cooled by liquid

nitrogen, has power in momentum/impulse/pulse 1-2 MW, duration of pulses 40 ns, recurrence of approximately 1000 momentum/impulse/pulses per second. Gas laser on molecular nitrogen has the more modest parameters: power in momentum/impulse/pulses 100 kW, a duration of pulses 10 ns and recurrence of 100 momentum/impulse/pulses per second. True, now is conducted intense work on an increase in the power of this generator. Generator on the second harmonic of ruby laser can have pulse power, which differs from its value in basic emission/radiation less than double.

SOUNDING CLOUDS.

Perhaps, it is possible with confidence to say that perhaps, it is possible with confidence to say that the laser sounding of clouds will be implemented into practice faster and it is wider than sounding other atmospheric parameters. To this contribute first of all the high values of the echo signal reflected, and also the practical need for having some data on the clouds which can be obtained with the aid of locators with the relatively modest parameters. Is important the fact that the particles of clouds have correct spherical form, and the index of their refraction is well known.

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Laser sounding of clouds gives the possibility: 1) with high accuracy tc measure lower cloud base and to investigate its space-time variability (during the use cf lasers, workers in conditicns/mode with the q-switching, the accuracy of the determinaticn of lower boundary to 1 m); 2) to determine the gecmetric and optical cloud thickness relatively low density (high-level cloud, noctilucent clouds) or average and high density, but small vertical extent (crder of several hundred meters); 3) to determine clcud height through the falling out from it residue/settlings; 4) tc measure the height/altitudes of the apex/vertexes cf the distant clcuds; 5) to measure lower boundary and vertical extent of high-level clouds through the breaks in the clouds cf the lower and average of decks; 6) to investigate the dynamics of crigin/ccnception/initiation and development of cloud; 7) to investigate the flocculent three-dimensional/space structure of clcuds and its variability.

All the enumerated problems can be solved and partially are solved with contemporary ones the laser sourding technique of the atmosphere and volume of our knowledge about the scattering properties of clouds. On Fig. 36, is given cne of the illustrations cf the application/use of lasers for determining lower boundary and

three-dimensional/space extent of the clouds of low density. In the lower part of the figure - airfoil/profile of the horizontal sectical view of the locality where were conducted measurements (state/staff California, USA). By triangle is marked the place where was located the laser locator, which pulsed at different angles in the vertical plane, which coincided with wind direction. In the upper part of the figure, are given the results of sounding the weak cloud layers at height/altitude from 8 to 12 km.

To each emission impulse correspond two points, one in lower boundary of cloud layer, the second - in upper. Exception is cloud layer with lower boundary at height/altitude of approximately 8 km. Its upper boundary was not determined due to the considerable vertical extent of layer.

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Cloud layers at the height/altitudes of 10-12 km "were x-rayed" by laser locator, although somewhere their extent on the course of momentum/impulse/pulse exceeded 2 km (for example, layer of locator to the left at a distance of 20-22 km on horizontal).

For practice it is important to also know concentration of particles, their according to sizes, water content of clouds,

volumetric coefficients of scattering and reflection, space-time picture of a change in these characteristics. Something in this direction it is already made. First of all, are designed volumetric coefficients of scattering and corresponding volumetric back-scatter factors of different types of clouds for two wavelengths of emission/radiation - 0.69 μ (laser on ruby) and 1.06 μ (laser on glass with neodymium). It turned out that for the most widely used types of clouds the ratio of back-scatter factors to coefficients scattering is characterized by within limits 30o/o.

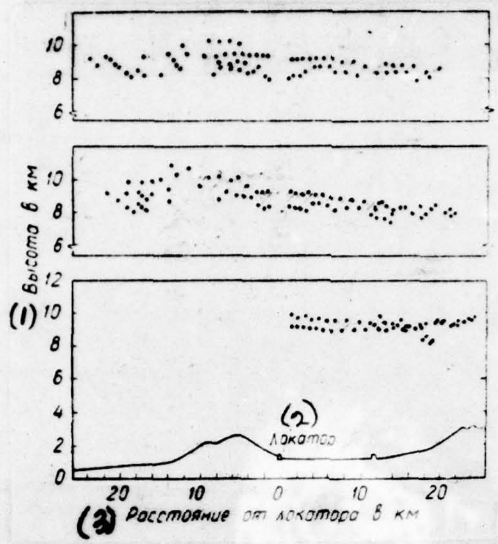

Fig. 36. Vertical section of cloud layers, obtained during laser sounding.

Key: (1). Height/altitude in km. (2). Locator. (3). Distance from locator km.

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Divergence to 30o/o is obtained only for one type of clouds, and for all others it was only 10-15o/o. The confirmation of these numerals of the experimental path will mean that from the echo signal reflected it is possible to directly extract information about volumetric coefficient of scattering.

An additional possibility of determining the volumetric coefficients of scattering clouds is connected with the study of a change in the shape of the reflected from cloud pulse. In our collective it is establish/installed the clearly expressed monotonic dependence between the coefficient of scattering cloud and all characteristics of the deformed echo pulse (width, edge steepness, maximum amplitude and time lag). This dependence can be used during the determination of the volumetric coefficients of scattering clouds in the strain of the echo from them laser pulses (Fig. 24).

As supplementary confirmation of the possibility of using the strain of the echo pulse for the quantitative estimation of volumetric coefficient of scattering serve the results of the calculations, carried out in the institute of optics of the atmosphere for the momentum/impulse/pulses of laser on ruby with the application/use of a method of statistical tests. Figure 37 illustrates one of the obtained results. Along the horizontal axis is plotted the time in microseconds, on vertical - logarithms of the intensity of the echo from cloud pulse. Curves are related to the values of volumetric coefficient of scattering by 0.02; 0.1 and 0.5 m^{-1}. Calculation is carried out for the cloud the sizes of particles of which are subordinated to gamma-distribution in most probable

radius 5 μ.

From the figure one can see that to the value of volumetric coefficient of scattering is very sensitive the slope/transconductance of leading edge and the half-width of the echo pulse. The analysis of other results of calculation showed that the shape of the pulse reflected is virtually insensitive to the half-width of the spectrum of the sizes of the particles of the cloud.

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Thus, it is possible to count that a question concerning the extraction of reliable information concerning the volumetric coefficients of scattering clouds from the results of their sounding by lasers can be solved during use by one of the examined procedures.

It is considerably more complex with determining of the microstructural characteristics of cloud. Apparently, effective means of the solution of this problem - multifrequency sounding which still is located in the quite initial stage of development. It is necessary to emphasize that the multifrequency sounding must begin from the theoretical development of the algorithm of the unique solution of the reverse problem, determining the wavelengths of sounding and

accuracy of measurements. At least, as a result of calculations theorists must find optimum conditions for sounding the microphysical parameters of clouds.

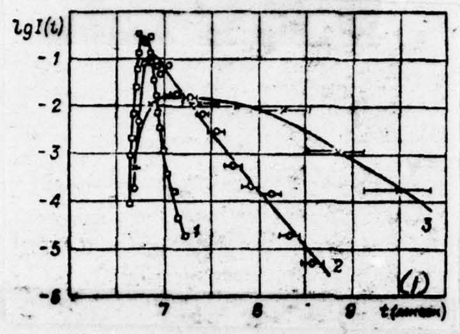

Fig. 37. Shapes of the reflected from clouds laser pulses at the values of volumetric coefficients of scattering by 0.2; 0.1; 0.5 m^{-1}. Along the horizontal axis is plotted the time in microseconds, on vertical line - logarithm of the intensity of the echo from cloud pulse.

Key: (1). t (μs).

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On the other hand, is necessary the development of the corresponding lasers. It is obvious, are promising the created recently sufficiently powerful/thick reconstructed generators on dye/pigments and the reconstructed parametric generators. Finally, it is possible to utilize solid-body lasers, that work on the harmonics of fundamental emission frequencies. At 4-th conference on the laser sounding of the atmosphere, they communicated on the creation of

four-frequency lidar, using lasers on ruby, glass with neodymium and them were second harmonics.

Even now it is possible to select necessary for sounding the clouds in the close ultraviolet, seen and by the nearest infrared regions generators, especially because requirement for radiation spectra in these cases flexible (provided to hit the narrow atmospheric window). In the regions indicated there is at least with tens of wavelengths of sufficiently powerful/thick laser emission/radiation, more or less than evenly distant from each other. More badly is matter with wave band from 2.36 to 10.6 μ.

SOUNDING OF ATMOSPHERIC POLLUTION.

The problem of fight with the contaminations of the atmosphere with each day becomes ever more actual/urgent. Therefore increasingly more acute/sharply is felt the need for the development of the ideal methods of the reliable quantitative estimation of the degree of contamination of the atmosphere. (Let us note that the ideally pure/clean atmospheres be cannot, yes even there are no need in this). Thus far none of the contemporary methods gives the operational estimation of the degree of air pollution on sufficiently wide three-dimensional/space and time/temporary scales.

The method of the quantitative estimation of the value of the surface finish of the atmosphere, instituted on the use of lasers, obviously, has large (no meanings).

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First of all, one should emphasize that with its aid it is possible not to only quantitatively rate/estimate the contamination of free atmosphere in any available to laser pulse of the localized region, but also to investigate in detail its space-time structure. Furthermore, this method makes it possible to establish/install the sources of contaminations and to rate/estimate their role in clouding of the atmosphere on different height/altitudes. The prospect of the method of the laser sounding of the contaminations of the atmosphere is caused by its high sensitivity. Indeed locator recovers echo signals from invisible ones by the eye of the particles of the aerosols with from relatively small concentration. Contaminations, as show the available data, create strong echo signals which are detected with locators with the sufficiently modest energy characteristics of lasers. For the illustration of the possibilities of laser sounding of the contaminations of the atmosphere, we give Fig. 38, on which shown space-time distribution of the contaminations of atmospheric boundary layer, received with the aid of laser.

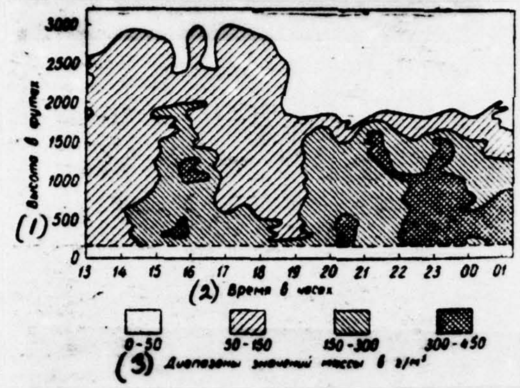

Fig. 38. Space-time picture of the contaminations of the atmosphere, obtained for 12 hours of laser sounding at height/altitude to 1 km.

Key: (1). Height/altitude in feet. (2). Time in hours. (3). Ranges of values of mass in g/m³.

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With the aid of lidars it is possible to probe the contaminations of the atmosphere not only aerosols of industrial origin, but also gas components. To this problem was dedicated a series of reports at the 4th conference on the laser sounding of the atmosphere. The greatest successes achieved Japanese researchers. They demonstrated the possibility in principle of the laser sounding of any soiling the atmosphere gas.

To the use of a laser echo method of the contaminations of the atmosphere are recently given all more attention. Extensive work in this direction are conducted in the USA and Japan.

Sounding density, temperature, and pressure of the atmosphere.

The determination of density, temperature and pressure has very important value, since these atmospheric parameters play the significant role in different atmospheric processes, including in weather and climate formation. One of the methods of the laser sounding of these connected parameters is instituted on the measurement of the echo signal reflected, caused by molecular scattering of light. As it was already noted, the measured during sounding volumetric back-scatter factor is unambiguously connected with volumetric coefficient of scattering, if we deal only with molecular scattering. In turn, volumetric coefficient of scattering is unambiguously connected with atmospheric density (by number of molecules per unit of volume).

Thus, if in experiments in some way it is possible to obtain the data on reverse molecular scattering, then from them are automatically obtained the data on atmospheric density. Density,

pressure and temperature of the atmosphere are connected by the definite analytical dependences, so that on the basis of the data on one of them it is possible to determine others. Knowing temperature and atmospheric density, with the aid of the appropriate equation without great work, we will obtain the value of pressure.

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As has already been mentioned, at height/altitudes from 30 to 60 km during the laser sounding of the atmosphere, was not reveal/detected perceptible contribution to the echo signal of the echo from the particles of the aerosols laser pulse. If we disregard the contribution of aerosols to echo signal, then it is possible to thoroughly calibrate the system of locator during measurements with any of the reduced height. More preferable, however, to take for calibration the height/altitude of 30 km, because, in the first place, the value of signal for it is more than for other height/altitudes of interval, secondly, this height/altitude they reach the radiosondes which can give the quantitative data on atmospheric density from direct measurements. Carried out thus calibration eliminates the need for the separate measurement of the transparency of the atmosphere, entering the equation of location.

A question concerning that, is it possible not to consider the

role of aerosols in the formation of echo signal of laser pulse at the height/altitude of 30 km, of course, it needs supplementary experimental confirmations. They can be obtained with sounding of the atmosphere with the aid of laser at wavelength 2.36 μ or during simultaneous sounding by any wavelength and precise measurement of atmospheric density by another independent method. It is indisputable, such proofs will be obtained.

The absence of the perceptible contribution of aerosols to the echo signal reflected still in no way indicates the absence of aerosols on the appropriate height/altitudes. Is completely permissible such situation, when the coefficient of aerosol weakening several times exceeds the coefficient of molecular scattering, but, nevertheless, the effect of aerosol scattering on echo signal incomparably less than the molecular. This occurs when for the probed wavelength of particle radiation of aerosols they possess the strongly elongated forward indicatrix of scattering.

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And if at the height/altitudes of 30-60 km we have precisely this case, then completely we can disregard aerosols, in spite of their existence in the perceptible, from the point of view of volumetric coefficient of scattering, quantities.

Let us give examples of the results of the laser sounding of the density of upper atmosphere (mesosphere), obtained by method indicated above. On Figs. 39-41, are represented the data of the soundings, carried out in state/staff Maryland (USA), in Winkfield (England) and in Kingston valve (jamaica). Errors do not exceed 3o/o for height/altitudes to 50 km (upper figure), 70 km (average figure) and 90 km (lower figure). This high accuracy is reached because of the addition of a large quantity of sent laser pulses.

From the illustrated here three cases of sounding only in one the radar echo reflected exceeded that expected upon consideration only of molecular scattering (height/altitude of 70-80 km).

Measurements in England reveal/detected the seasonal dependence of echo signals at height/altitudes from 50 to 90 km. The difference in the absolute values of signals composed approximately 50-60o/o. In summer signals are more, but less than are in winter average annual ones by 25-30o/o.

let us give an additional one interesting example of sounding the density of upper atmosphere, carried out in Kingston valve. Its results are depicted on Fig. 42. Measurements continued 2.5 hours.

For this time in the atmosphere, were sent 300 momentum/impulse/pulses. For figure distinctly evident the divergence cf the measured echo signals frcm those designed for height/altitudes frcm 45 km and it is above which wavily increased with height/altitude, reaching at height/altitude cf approximately 100 km cf maximum value - more than 10Co/o. The authors of this experiment supposedly explain discovered wavy nature of the echo signal reflected by effect on upper atmosphere of the Earth tides. On the reascns for divergence itself nothing defined, apparently, cannot be said, since it can be caused by both the aerosol layers and change in the density of the pure/clean atmosphere.

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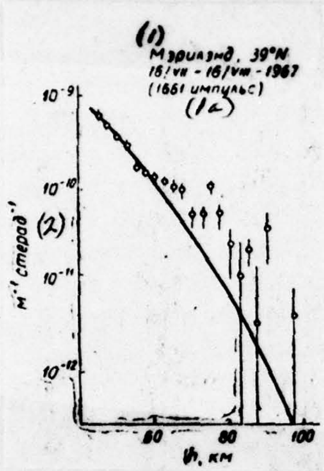

Fig. 39.

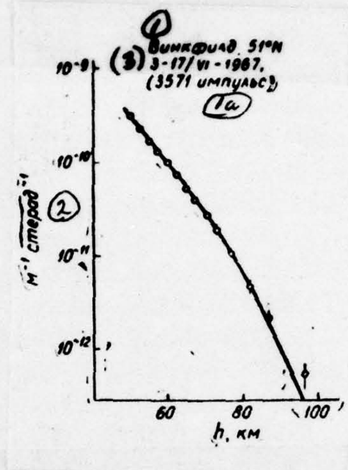

Fig. 40.

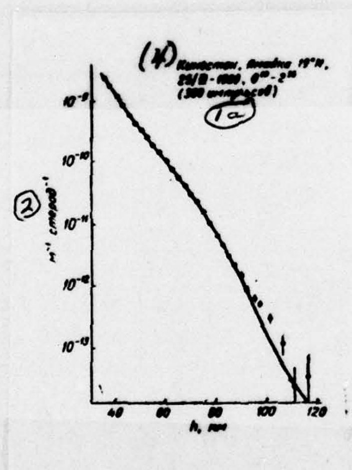

Fig. 41.

Figs. 39, 40, 41. Data of soundings of mesosphere, carried out near Washington (USA), in Winkfield (England) and in Kingston valve (Jamaica). In all three figures the results of sounding are

represented by points with the passing through them vertical lines whose length speaks about measuring errors. Unbroken curves reflect the dependence of the function of reverse molecular scattering on height/altitude on the standard model of the atmosphere.

Key: (1). Maryland, 39°N. (1A). momentum/impulse/pulse. (2). sterad^{-1}. (3). Winkfield 51°N. (4). Kingston, Jamaica 19°N.

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On Fig. 43, is shown the dependence of temperature on height/altitude, obtained on the basis of the analysis of the results of the laser sounding of atmospheric density at height/altitudes from 50 to 80 km in Winkfield.

All the examined above results of sounding the density were related to mesosphere, since to isolate molecular scattering at these height/altitudes is relatively simple, if we proceed from the assumption about the extremely small role of aerosol scattering in the formation of the echo signal reflected. At height/altitudes to 30 km aerosol scattering significantly affects echo signals, and thus far still it is not possible to sufficiently accurately separate/liberate it from molecular. During processing of the results of sounding in the lower 30-kilometer layer of the atmosphere, the

molecular scattering is considered not changing in time in conformity the standard model of the atmosphere.

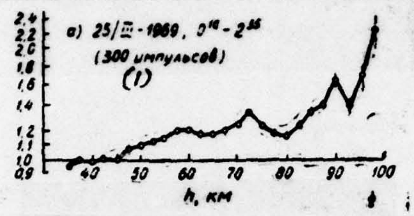

Fig. 42. Results of **sounding the density** of mesosphere, obtained in Kingston (Jamaica). Along the horizontal axis are plotted the values of height/altitude, on vertical - ratio of the observed echo signal to that designed by the standard model of the atmosphere taking into account only molecular scattering.

Key: (1). momentum/impulse/pulses.

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In conclusion let us note that the data on density, temperature and pressure during the laser sounding of the atmosphere in principle can be obtained on the basis of the very fine/thin investigations of the echo signal reflected within the limits of the duct/contour of the line of the absorption of any atmospheric gas.

In chapter about the absorption of laser emission/radiation by atmospheric gases we, in particular, examined the dependence of the duct/contour of the lines of absorption on pressure and temperature. Both pressure and temperature affect the form of duct/contour and half-width of the line of absorption. Thoroughly investigating the form of duct/contour and half-width of the line of absorption during scattering of emission/radiation from different height/altitudes, it is possible to solve the inverse problem - to find the corresponding to them values of pressure and temperature.

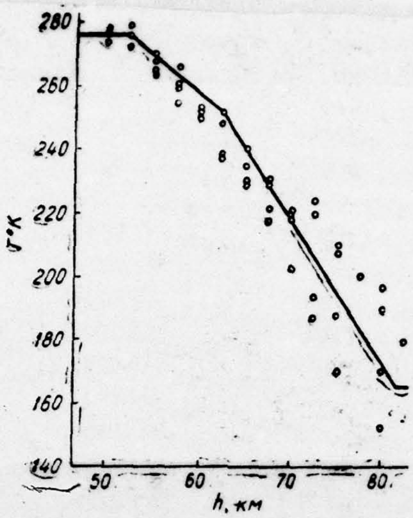

Fig. 43. Dependence of temperature on height/altitude. Points designated the values of temperature, obtained from the results of sounding. Unbroken curve is constructed according to the standard model of the atmosphere.

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Idea this thus far nowhere was voiced nor was utilized, it is possible in connection with the great difficulties of realization. Indeed first of all will be required laser with the reconstructed frequency within the limits of the duct/contour of the specific line of absorption and it is simultaneous with the extremely high degree of monochromaticity (order 10^{-3} cm^{-1}).

SOUNDING HUMIDITY AND OF THE CONCENTRATION OF DIFFERENT ATMOSPHERIC GASES.

Sounding the concentration of the molecules of water vapor and other gas atmospheric components can be carried out: 1) during the measurement of the echo signal reflected at two closely spaced wavelengths, one of which is given to center of the line of the absorption of the corresponding gas, and another is arrange/located together, out of the line of absorption; 2) during the use of resonance scattering of the laser emission/radiation when the wavelength of the latter coincides with the intense line of the absorption of atmospheric gas with the short lifetime of atom or molecule of this gas in excited state and, the consequently extremely rapid re-emission of the absorbed light quantum with the same frequency; 3) on Raman scattering with which the molecules of atmospheric gas are exchanged with energy with the falling/incident light quantum and in echo signal together with the frequency of the falling/incident quantum, there is considerably more low-level radiation with another frequency.

In spite of importance of information about the airfoil/profiles of the concentration of different atmospheric gases and relative simplicity of the procedure of its extraction during the use of any of three named methods, we dispose of extremely meager data.

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This, first of all, it is explained by the contemporary level of development of laser technology.

Was undertaken by one more or less successful attempt at the use of a pulse laser on ruby for sounding the high-altitude distribution of the concentration of water vapor. Sounding was carried out by two momentum/impulse/pulses, the wavelength of one of them (0.69438 μ) coincided with the center section of the line of absorption H_2O, the wavelength of another differed in all on 0.5-1.0 cm^{-1} but it fell between the lines of absorption. Since back-scatter factors for these wavelengths do not in practice differ, then from the equation of laser location is not difficult to obtain the sufficiently simple formula on which it is possible to determine the distribution of water vapor with height/altitude, if are known echo signals.

In this way it was possible to obtain the elevation profile of humidity for the lower 4-kilometer layer of the atmosphere.

The phenomenon of Raman scattering was used for sounding the airfoil/profile of the concentration of molecular nitrogen - the

basic atmospheric component. The source of generation was a ruby laser in wavelength of emission/radiation 0.6943 μ. The line of Raman scattering of the molecule of nitrogen had length of emission/radiation 0.8285 μ. The height/altitude of sounding did not exceed 10 km, since the intensity of this line approximately to 3 orders is lower than the intensity of molecular scattering at this same wavelength.

During sounding of the atmosphere by pulse laser on molecular nitrogen (wavelength of emission/radiation 0.3371 μ) it was possible to record the lines of Raman scattering of the molecules of nitrogen (wavelength 0.3658 μ) and of oxygen (wavelength 0.3557 μ). The height/altitude of sounding is less than 10 km.

Resonance scattering was used for sounding vapors of sodium in upper atmosphere.

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This example magnificently demonstrates the possibility of the method of the laser sounding when is applied generator with the necessary parameters. In sodium, atoms exist two intense lines of emission/radiation in wavelengths 0.5890 and 0.5896 μ (famous doublet of sodium). In experiments was utilized a dye laser with the

reconstructed by wavelength of emission/radiation. Thus, it proved to be possible to probe the atmosphere by the emission/radiation the wavelength of which coincided with one of the lines of the doublet of sodium. Sounding only did not make it possible to reveal/detect sodium at height/altitude from 80 to 100 km, but also to measure its concentration, distribution with height/altitude and to investigate the space-time distribution of vapors. But indeed the maximum concentration of vapors of sodium comprised the billionths of the concentration of nitrogen and oxygen at these altitudes! Let us note that the obtained average high-altitude airfoil/profile of the concentration of vapors of sodium corresponded to that depicted in Fig. 1, obtained by another method.

In conclusion let us formulate basic requirements for lasers for sounding atmospheric gases. The main things and most rigid of them are related to the radiation spectrum of generators. It must be simultaneously and high-monochromatic (width of emission/radiation must not exceed the hundredth of kayser), and have predetermined with accuracy not less than 0.01 cm^{-1} wave length constant of emission/radiation. Requirements for power and energy of momentum/impulse/pulse the same as during sounding of other atmospheric parameters. The greater the pulse energy, the higher the ceiling of sounding.

The success of sounding atmospheric gases also depends substantially on the level of our knowledge about the true duct/contour of the spectral lines which will be utilized in practice, including from the perfection/improvement of the methods of laser spectrometry.

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SOUNDING TURBULENT HETEROGENEITIES AND OF THE WIND IN THE ATMOSPHERE.

During the propagation of laser emission/radiation in the turbulent atmosphere, occur the fluctuations of amplitude and phase, which cause in turn, the fluctuations of intensity, angle of arrival, transverse of intensity, angle of arrival, the cross section and other parameters of beam. These fluctuations depend on the intensity of turbulence, the internal and external scales of the heterogeneities of the spectrum of the fluctuations of the rate in the turbulent flow and the connected with it spectrum of the micropulsations of temperature and refractive index, on average wind speed. Therefore in principle on the basis of the measurements of the statistical characteristics of the random distortions of the parameters of laser beam, it is possible to determine the characteristics of atmospheric turbulence and wind velocity.

Let us examine some of the possible diagrams of the remote determination of the parameters of gustiness, instituted with the use of lasers. Let us begin from the determination of the value of the intensity of turbulence, which has widest practical application/use. This value is characterized by the so-called structural constant of refractive index.

One of the simplest methods of determining the structural constant of refractive index is based on the measurements of the "vibration" of image in the focal plane of the telescope, which accepts the beam of laser emission/radiation, which passed the specific layer of the turbulent atmosphere. Accordingly of known from the literature approximation formula, dispersion of the vibration of the image of laser it is connected with the structural constant of refractive index, the thickness of the layer of the atmosphere between the laser and the telescope and the diameter of telescope. Measuring the dispersion of the vibration of image and knowing the distance between the source and the receiver and the diameter of receiving system, it is possible without the special work to determine the structural constant of the refractive index of air.

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The block diagram of the corresponding experimental installation is

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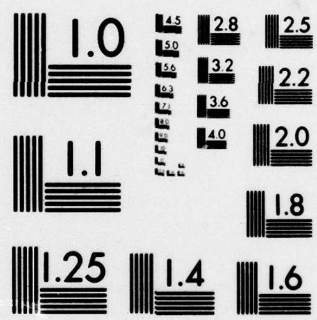
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1.4
1.6

develcped in our collective. Testings of installation itself it gave satisfactory results.

The described diagram makes it possible to find the structural constant of the refractive index of the specific layer of the atmosphere between the source and the receiver. In practical activity it is frequently necessary to know the airfoil/profile of structural constant on the course of laser beam. The expression, which connects the depending on coordinates structural constant of refractive index with the dispersion of the fluctuations of the logarithm of amplitude on the axis of beam, is the integral equation which can be solved only numerically. For sufficient accuracy and uniqueness of this solution, it is necessary to utilize special mathematical methods. Thus far this problem is not solved.

If is known the distribution of the structural constant of refractive index, then after measuring the so-called space-time correlation function of the intensity of the world/light, arriving from star, in principle it is possible to find the distribution of the values of wind velocity with height/altitude. Discussion deals with the use of a known phenomenon of winking of stars which each of us observed repeatedly. Problem this also far not simple, since communication/connection between values indicated above is expressed by the integral equation, which yields only to numerical solution

with this all escape/ensuing from difficulties.

Together with the diagrams of the investigation of the turbulence characteristics of the atmosphere, instituted on the use of statistical correlation analysis, it is possible to utilize also the idea, which is based on the Doppler effect of the frequency of the laser emission/radiation, scattered by the driving/moving reflectors (aerosol particles, molecules, artificially introduced in the atmosphere by admixtures).

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The Doppler effect of the emission frequency, reflected on hydrometeors, successfully is applied in radar for determining average wind speed and its pulsations. The use of this phenomenon in optical wave band promises a whole series of advantages. Due to the considerably more high frequency of optical radiation, with respect grow/rises Doppler frequency shift. In optical range substantially grow/rises spatial resolution of sounding at any time, and to any to practically important height/altitude is a sufficient quantity of scattering centers, are well studied mechanisms, and finally it is possible with confidence to assume that these scattering centers are completely carried along together with air masses, i.e., the rate of their displacement/movement can be considered as equivalent wind velocity.

However, to utilize the Doppler effect in optical range is sufficiently difficult. First of all, it is masked the spectrum of the Doppler effect of emission frequency, caused thermal agitation of molecules, turbulence and Brownian motion of the particles of the aerosols. True, this difficulty it is possible to avoid to a considerable extent, if to go on path that of the called superheteroidal reception of signals, but for this they are necessary lasers with large time coherence and sufficient energy. Thus far with the superheteroidal method it is possible to achieve the distances of sounding on the order of 100 m.

Finally, let us note the possibility in principle of the laser sounding of the parameters of atmospheric turbulence on the basis of the measurements of echo signals, caused by scattering on the small-scale heterogeneities of the turbulent atmosphere.; however, even here not all is simple. As show calculations, intensity of the scattered from turbulent heterogeneities signal on many orders less than during the molecular scattering of laser emission on ruby.

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At the 4th conference on the laser sounding of the atmosphere,

were heard two reports, dedicated to sounding wind velocities. In one case it was conducted during the use of the Doppler effect, in other - on the basis of correlation statistical analysis.

In both cases the first experimental results testify to the prospect of the proposed echo methods of wind velocity.

LASER SOUNDING OF THE ATMOSPHERE FROM SPACE.

All the examined above problems of the laser sounding of the atmosphere from the Earth virtually can be solved with the aid of the locator, placed on board artificial Earth satellite or, it is still better, at orbiting space station. Definite advantage of this sounding - possibility of the investigation of different atmospheric parameters in planetary scale. In this case, the distances of sounding noticeably grow/rise, since energy of momentum/impulse/pulse does not attenuate in near kosmos. From onboard of orbital station, is open/disclosed the possibility of sounding different parameters of upper air to which from the Earth virtually it cannot be reached due to the large energy losses, caused by interaction of laser pulse with the lower dense layers of the atmosphere.

During sounding of the atmosphere from kosmos, it is easy to determine the upper cloud boundary and to investigate the dynamics of

its variability. Clouds themselves impede sounding only subcloud layer of the atmosphere. With the cloudless atmosphere the sounding can be carried out up to the surface of the Earth.

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It is in parallel with sounding atmospheric it is possible with high accuracy to determine distance of different points of the earth's surface and even - to investigate the transparency of different basins. The sensitivity of sounding from kosmos will increase substantially, if we in the specific point/items on the Earth establish/install equipment/devices for the method of locating laser pulses. In this diagram of energy of one momentum/impulse/pulses, completely it will be sufficient to that in order to write continuous echo signal on an entire route from laser at space station to the Earth.

On the path of the practical embodiment of potential possibilities indicated above of the laser sounding of the atmosphere from space, will create a series of serious, but completely surmountable interferences. To the examined previously difficulties of the problem of the laser sounding of the atmosphere from the Earth here are added their specific, which are first of all connected with the even low energy characteristics of lasers in recalculation per

the unit of their weight. However, development of laser technology rapidly moves hope to the fact that first experiments in the laser scunding of the atmosphere from onboard of orbiting space station will be carried out already in the near futcre.

EVALUATICN OF THE POSSIBILITIES OF THE LASEF PROBE OF THE ATMOSPHERE.

With an increase in the distances cf the probed volumes of the atmosphere, sufficiently rapidly decreases the value of the echo signal of laser pulse reflected. This, mainly, it is caused by the inverse proportional dependence of the value of echo signal from the square of distance to scattering volume. The fact is that the probed volume of the atmosphere scatters emission/radiation in different directions of space, and to the receiving mirrcr of locator falls cnly its insignificant part. It is equal to the ratio/relation to the area of mirror to the area cf the imaginary sphere whose radius is equal to distance of scattering volume.

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So, if the area of receiving mirror is equal to 1 m^2, then from distances cf scattering volume 1, 10 and 10C km it will record respectively $8 \cdot 10^{-8}$; $8 \cdot 10^{-10}$; $8 \cdot 10^{-12}$ by porticn scattered by the vclume of energy. The numerals indicated are obtained on the

assumption that the probed volume scatters energy of laser pulse evenly in different directions. But in reality of the particle of atmospheric aerosols in backward direction scatter energies less than on the average in different directions, besides the lesser than is more elongated forward their indicatrix of scattering, i.e., the greater their size/dimensiors in comparison with the wavelength of the scattered emission/radiation. During molecular scattering in backward direction, it is scattered 1.5 times more than on the average in different directions.

It emerges, the range of laser locator depends substantially on distance and cannot be boundless. In work in real atmosphere, it is considerably less in comparison with theoretically possible. The actual range of laser locator is determined by the value of the ratio of echo signal to the signal of noise or interference. The signal of noise is composed of noise signal of atmospheric origin and signal of the inherent noise of radiation detector (the photomultiplier).

Useful signal is directly proportional to initial pow and duration of emission impulse, the area of receiving mirror, to volumetric back-scatter factor, to square of the transparency of the layer of the atmosphere between the probed volume and the receiving system and is inversely proportional to the square of the length of this layer. Thus, desiring to increase useful signal for the

fixed/recorded distance between the scattering volume and the receiver, we must increase either energy of transmitted pulse or area of the receiving mirror (both of characteristics equally enter into the equation of location, i.e., an identical change in each of them leads to one and the same a change in the useful signal).

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By the appropriate selection of the wavelength of emission/radiation we can decrease the action of the factor of the transparency of the atmosphere on useful signal and find optimum conditions for a volumetric back-scatter factor.

Noise signal of atmospheric origin is connected with scattering of solar radiation in daytime, with night glow, with scattering of the emission/radiation of artificial sources, including sounding pulse, in particular in the lower, densely filled by aerosol particles layers of the atmosphere. Its own selective emission/radiation of the atmosphere also affects noise signal of atmospheric origin.

To decrease the noise signal of atmospheric origin it is possible: 1) after using the narrow-band interference filter before the radiation detector (however the narrower the filter pass band,

the more difficultly it is to attain its good transparency); 2) decreasing the field-of-view angle of the receiving system (useful signal in this case does not change, but noise signal decreases inversely proportional to the square of the field-of-view angle).

The signal of the noise of the photomultiplier depends substantially on the quality of instrument and on the temperature, at which it works. Therefore during sounding of upper air when useful signal is obtained as a result of the statistical accumulation of the reflected from the specific height/altitudes photons with a large quantity of sent emission impulses, for decreasing the inherent noise of receiver, are utilized the specially selected or prepared copies of photoelectric multipliers the strength of noise current of which can be additionally decreased because of their cooling.

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Let us give examples of ranging of the action of some real systems of the laser sounding of the atmosphere. Figure 44 depicts the results of the calculation of a quantity of photons which are detected from height/altitudes in range from 30 to 100 km by two systems of the laser locators, utilized in Kingston valve on jamaica, with the message of one laser pulse and transparency of the atmosphere, equal to 70o/o. The parameters of systems are given in Table 8.

On figure by solid lines are depicted dependences indicated above. It is assumed that the echo signal is form/shaped only because of reverse molecular scattering. Broken lines show the average noise signal levels from night sky (4 and 2 levels for the 1st and 2nd systems), from daytime sky for the 1st system (level 1) and the signal of the inherent noise of the photomultiplier (level 3).

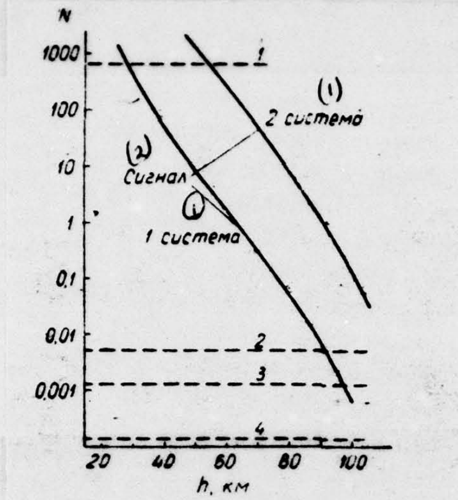

Fig. 44. Quantity of photons, detected from height/altitudes from 30 to 100 km by two systems of laser locators.

Key: (1). system. (2). signal.

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Noise signals were counted under the following assumptions: the passband of interference light filter was equal to 10 Å, the field-of-view angle of receiving system 1 mrad (3.4 angular minute), the inherent noise of photomultiplier was equal to 100 photons per second (which can be reached during the appropriate cooling of receiver). Was considered only night glow.

It is not difficult to note that in the work with the night when it is possible to disregard the effect of the noise, caused by artificial radiation sources in the atmosphere, for the examined systems noise factor does not have any significant influence at the height/altitudes below 80 km. In the daytime of system, they are operational only at height/altitudes to 20 km. The use of a more narrow-band interference filter, smaller field of the view of receiving system, and also light polarizing filters will indisputably increase the ceiling of sounding; however, there are no foundations for expecting that it will achieve its value, characteristic for night time.

Table 8. Characteristics of the jamaica systems of the laser sounding of the atmosphere.

(1) Параметры	(2) Един. измерения	(3) 1-я система	(3) 2-я система
(4) Энергия в импульсе	(5) дж (6) фотоны	5 $1{,}75 \cdot 10^{19}$	20 $7 \cdot 10^{19}$
(7) Площадь приемной антенны	$м^2$	0,25	5
(8) Интервал высот интегрирования при подсчете фотонов	км	2	2
(9) Интегральная эффективность (к. п. д.)	%	1	2
(10) Частота следования импульсов	(11) импульсов в час	100	200

Key: (1). the parameters. (2). It is single, measurement. (3). system. (4). Pulse energy. (5). J. (6). photons. (7). Area of receiving antenna. (8). interval of height/altitudes of integration during calculation of photons. (9). Integral effectiveness (efficiency). (10). Pulse repetition rate. (11). momentum/impulse/pulses in hour.

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Let us recall that the depicted on the figure quantity of photons, detected by the detection systems of locators with the message of one emission impulses, is related to 2-kilometer intervals

of height/altitudes. Thus, looking at figure, we can say that at height/altitudes it is more than 60 km for the first and more than 90 km for the second system from one sent momentum/impulse/pulse of 2-kilometer layers come less than on 1 photon. Therefore confident determining of the probed characteristics of the atmosphere is possible with the statistical accumulation of the photons, reflected from the appropriate height/altitudes, with the message of a sufficient quantity of momentum/impulse/pulses. Table 9 gives those designed for the examined above two systems of the laser sounding of the value of a quantity of detected photons from height/altitudes from 40 to 100 km during the one-hour period of their work. Simultaneously for each of the height/altitudes are shown the corresponding measuring errors.

From the table of form, that the 1st system per hour of work capable of carrying out a measurement with an accuracy to 10o/o at height/altitudes not more than 70 km.

Table 9. Quantity of detected photons for Jamaican systems of laser sounding.

(1) Высота, км	(2) 1-я система		(2) 2-система	
	(3) колич. фотонов	(4) ошибка, %	(3) колич. фотонов	(4) ошибка, %
40	4500	1,5	1400 000	1,0
50	750	3,5	240 000	1,0
60	150	9	48 000	1,0
70	35	18	10 000	1,0
80	6	40	2 000	2,0
90			250	6,0
1000			30	20,0

Key: (1). Height/altitude, km. (2). 1st system. (3). quantitative photons. (4). error, o/o.

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Per sounding at high altitudes with the same accuracy, it is necessary to increase operating time or to decrease the field-of-view angle, or to increase the interval of the height/altitudes, from which are summarized the photons reflected. In this case, it cannot be forgotten that the accuracy of sounding grow/rises directly proportional to square root of the appropriate improvement. So, if operating time is increased 4 times, then measuring errors decrease only 2 times.

The 2nd system provides per hour of work the accuracy of

measurement to 1o/o to the height/altitude of 70 km and only at the height/altitude of 100 km its accuracy deteriorates to 20o/o.

Let us note that recently the area of the receiving antenna of lidar in Kingston valve on Jamaica was led to 16 m².

Let us give some considerations about advisability and prospect of the use of a laser on fluorite with dysprosium (wavelength of emission/radiation 2.36 μ) for sounding upper atmosphere, in this case during the emission/radiation of the process of the formation of echo signal, reflected from any height/altitudes, it is possible to disregard molecular scattering.

Let us consider that the volumetric coefficients of aerosol and molecular scattering in the visible region of the spectrum at height/altitudes of more than 60 km are approximately identical. This completely corresponds to the majority of data, obtained by different methods. Moreover, these data they indicate that the aerosol coefficients at the height/altitudes indicated are more than molecular ones. The sizes of the particles of the aerosols let us consider included between 0.1 and 1.0 μ and distributed according to formula Young.

This assumption also is based on the appropriate data, published

in press/printing.

In this case volumetric coefficients of scattering for wavelengths 2.36 and 0.69 μ differ for the model of the particles of the aerosol in question approximately 4 times (see Table 6). For laser emission on ruby, this coefficient is more.

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But if we examine volumetric back-scatter factors, then as a result of considerably larger on the average of the elongation of the indicatrix of scattering of particles for a wavelength 0.69 μ echo signal from momentum/impulse/pulse in wavelength 2.36 μ will be approximate the same as from momentum/impulse/pulse in wavelength 0.69 μ.

Taking into account the made assumption it is possible to calculate the effectiveness of the work of locator on laser in wavelength 2.36 μ and to compare it with the effectiveness of the examined above systems of locators. Energy of the momentum/impulse/pulse of laser on fluorite 0.04 J. If we with this laser replace ruby generators in the examined above locating systems, assuming that all the remaining parameters remain the same, then instead of the hour of work for achievement of the same effectiveness

will be required with respect to 100 and 12 s.

The given calculations, of course, bear very tentative character. But also they show the unconditional advisability of the creation of the new laser probes of the atmosphere on the basis of generator on fluorite with dysprosium which, out of any doubt, will make it possible to investigate the reflection of emission/radiation from aerosols, not virtually burdend by the effect of molecular scattering on any to it available height/altitudes. it is obvious, the ceiling of sounding the atmosphere such locator will be sufficient to high ones, if we know how to create radiation detector with the parameters, close to the parameters of the photomultipliers.

Today the best specimen/samples of new receivers on sensitivity thus far are inferior to the photomultipliers approximately to 1 order.

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Let us total. Although the laser sounding of the atmosphere is located in the early stage of development, nevertheless already it is possible to speak about practical results and to present at least the approximate picture of the future of laser atmospheric probes. The existing systems of the laser sounding of the atmosphere capable of

sclving and to some degree already solve the following problems.

1. Study of stratification and relative density of layers of atmospheric aerosols and their space-time variations to height/altitudes on the order of 30 km at any time of days.

2. Determination of space-time cut/sections of contaminations of atmospheric boundary layer by industrial impurity/admixtures and impurity/admixtures from other sources.

3. Sounding density, temperature and pressure at height/altitudes from 30 to 100 km. Study of changes in the density of the upper air, caused tides and internal gravity waves.

4. High-precision determination of lower boundary of cloud layers; estimation of liquid-water content of lower part of clouds; determination of vertical extent of clouds of low density, including silver ones; sounding clouds upper and average of decks through discontinuity/interruptions in cloudiness of lower deck.

5. Determination of elevation profile of humidity in lower 3-4-kilometer layer of atmosphere.

6. Study of distribution of the concentration of nitrogen and

oxygen in lower ten-kilometer layer of atmosphere.

7. Analysis of the concentration of atoms of sodium and its space-time changes at height/altitudes from 80 to 100 km.

8. Study of concentration of soiling atmospheres gases at least abcut sources of contamination.

As yet there are no these calculations of the economic effectiveness of the methods of the laser sounding of the atmosphere, but already purely quantitative estimations show that these methods will be considerably cheaper than the aircraft, and thereby of rocket sounding.

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They already, apparently, are competitive with the mass echo method of the atmosphere - with the aid of water-filled spheres with the suspended/hung to them radiosondes.

VIEW INTO THE FUTURE.

As far as future is concerned, is here indisputable one: the laser sounding of different atmospheric parameters has large

prospects. Indeed discussion deals with the fundamentally new method of the remote study of different atmospheric phenomema in the troposphere, the stratosphere, the mesosphere and the ionosphere. The diverse most interesting potential possibilities of this method the faster will be personified into practice, the rather will be decided two basic problems, which directly affect the progress of the remote study of the atmosphere with the aid of lasers. We bear in mind the creation of new locating systems and the development of the mathematical algorithms of the single-valued extraction of information about the atmospheric parameters from the results of sounding.

New laser locating systems first of all must be constructed with the use of an idea of the multifrequency sounding of the atmosphere. This idea can be realized either with the aid of lasers with the reconstructed frequency, or series of lasers with discrete frequencies. It is possible that it is necessary in one and the same system to utilize those and other lasers. Picture appears when theorists, who develop/process the problem of the single-valued extraction of information, call/name to the developers of equipment the enumeration of the wavelengths, necessary for solving different specific problems.

The second important part of the equipment problem is an

increase in energy and pulse repetition frequency. In this case, an increase in these parameters must, as a rule, occur with the preservation/retention/maintaining of the duration of the emission impulses of the order of several ten nanoseconds, otherwise we will lose in spatial resolution.

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Finally for the realization of many specific problems of the laser sounding of the atmosphere, it is necessary to create special lasers, whose giant power and high energy of emission impulse are combined with narrowness and stability of radiation spectrum.

Simultaneously with an improvement in the parameters of lasers must be improved and the parameters of receiving systems, namely, threshold sensitivity and noise receiver responses of emission/radiation, the bandwidth and the transparency of interference filters. As far as diameter is concerned of inlet (antenna) and of field-of-view angle, here the question does not deal with the improvement of the parameters, but about the use of their advisable values during the solution of one or the other specific problems.

In new locating systems must widely be utilized the

polarizational equipment/devices, necessary both for the extraction of information from the results of sounding and for decreasing the interference effect of atmospheric origin.

Finally, the extremely important component/link of new systems must become the block/module/unit of recording and operational processing of the echo signals of laser pulses reflected, which includes equipment/device for amplifying the signals proportional to the square distance, pulse-height analyzer of the airfoil/profile of the intensive signals, input equipment into electronic computer - machine itself and attachment for the conclusion/derivation of the results of processing information (for example, the plotter of the airfoil/profiles of the probed atmospheric parameters).

The problem of the development of the mathematical algorithms of the single-valued extraction of information about the atmospheric parameters from the results of sounding is not less complex, than equipment problem, although by it are occupied the considerably more modest forces.

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Therefore appears danger, that the rates of the development of the laser sounding of the atmosphere will be at larger degree restrained

by delay at the solution of the reverse problem during sounding of the concrete/specific/actual atmospheric parameters. Consequently, this problem requires to itself more considerable attention how by it it was given, until now.

Now we will try to draw the approximate qualitative picture of the development of the methods of the laser sounding of the atmosphere in the foreseeable future. It is completely possible that it will seem excessively optimistic in the sense of the periods (nature fairly often presents to the researchers of unexpected contingency), but the author it would very want to believe in its validity.

As with any forecast/prediction, let us begin from the characteristic of the problems whose solution can be expected in the near future, let us say after 3-5 years. To their number we is related following.

1. Sounding stratification of aerosol layers and their relative density at height/altitudes is more than 30 km.

2. Simultaneous sounding of atmosphere with use of emission impulses with several wavelengths for separation of the components of the echo signal, obliged to aerosol and molecular scattering, and

determinations of elevation profile of aerosol and molecular coefficients of scattering at height/altitudes to 30 km.

3. Determination of vertical density profiles, temperature and of pressure at height/altitudes to 30 km on basis of corresponding airfoil/profiles of coefficients of molecular scattering or during use of phenomena of resonance and Raman scattering.

4. Increase in ceiling of sounding humidity approximately to height/altitude of 30 km.

5. Determination of coefficients of scattering and of effective sizes of particles and their variations with height/altitude in lower part of clouds lower and average of decks.

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6. sounding lower and upper boundaries, high-altitude airfoil/profile of coefficient of scattering and optical thickness of high-level clouds, including noctilucent clouds.

7. Determination of elevation profiles of concentration of different atmospheric gases on basis of use of resonance absorption and scattering and Raman scattering and lasers with reconstructed

emission frequency. On the ceiling of sounding different gases as yet nothing that determined it is not possible to say.

8. Detailed investigation of contaminations of atmospheric air by products of industrial activity of man.

With the solution of the enumerated problems will be simultaneously be improved the methods of studies and raised the accuracy of the determination of those atmospheric parameters which will be probed at present. With a sufficient energy of the researchers and developers of equipment in the coming five-year period, it is possible to expect the appearance of the first specimen/samples of laser meteorological locators in series performance.

In the following 5-10 years it is possible to rely on the consecutive solution of such most complex problems as sounding concentration, refractive indices, the spectra of the sizes of the particles of the atmospheric aerosols (clouds, mist/fogs, mists, residue/settlings), and also the analysis of the structure of atmospheric turbulence and wind velocity. One should expect that, together with the wide development of the methods of laser sounding from the earth/ground, during this period will be begun the practical use of laser atmospheric probes from onboard of lasting space orbital

stations. Simultaneously must appear the second generation of laser meteorclogical locators - with the operational processing of measurable data and the readout of sounding in the form of the airfoil/profiles of the corresponding atmospheric parameters or of the significant figures of these parameters at the specific standard levels in the atmosphere.

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Depending on the complexity of the solved problem, processing the results of sounding can be carried out by the computer, built in into laser locating system or by the equipped communication channel with arranged/located elsewhere computer.

Further development of the methods of the remote sensing of the atmosphere with the aid of lasers must lead to the creation of meteorological laser locators with the virtually fully automated cycle of work and with remote control. The results of sounding the atmosphere in suitable for direct use during calculations of weather forecasts form will automatically enter the data processing centers.

In conclusion let us examine a question concerning the place of the laser sounding of the atmosphere among other methods of the remote determination of different atmospheric parameters.

The known at the present time methods of the remote sensing of the atmosphere it is possible to divide into four types: the acoustic, microwave, laser, passive sounding of the atmospheric parameters on the outgoing into kosmos emission/radiation. Not one of them it is not possible to call/name universal. In each exist their pluses and minuses, and, logically, they will supplement each other. However, in a quantity of potential possibilities of sounding different atmospheric parameters the methods of laser sounding, undoubtedly they will cost on the first place. This is explained by the fact that interaction of optical waves with atoms and molecules of atmospheric gases, with the particles of atmospheric aerosols, with the heterogeneities of the turbulent atmosphere is accompanied by the wide spectrum of the diverse easily recorded phenomena.

However, in the laser sounding of the atmosphere, exists one very essential deficiency/lack: with the overcast the ceiling of sounding from the Earth is limited by cloud height, and therefore method proves to be all-weather.

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The overcoming of the deficiency/lack indicated can go, at

least, in two directions: the simultaneous sounding of the atmosphere frcm the Earth and frcm kosmos and sounding through the clear channel in cloud, obtained under the influence cf high-power laser pulse or pulse train directly before the message of sounding pulse. Both of paths (especially first) are ccmpletely prcmising, although about their practical realization it passes considerable time.

One should emphasize that it would be the as unpardonable fallacy consider that the methcds of the laser sounding of the atmospheric parameters of screens all problems of the investigation of the atmosphere. It goes without saying, their introduction into practice will lead to the incontrovertible progress in the study of manifold atmospheric phencmena. Unquestionable that on the way of achieving this progress it is necessary to overcome many difficulties.

Finally, several words abcut the cost indices of different types cf the remote sensing of the atmosphere. Although all methods are located in the stage of develcpments and still early news the corresponding economic calculaticns, nevertheless it is important to emphasize that the laser sounding of the atmosphere according to cost indices is completely competitive with all cther methods of the remote investigaticn of the atmospheric parameters. To the competence/validity of this ccnfirmaticn, testifies rapid development

of laser technology and connected with it systematic reduction in its cost/value.

The rapid progress of quantum electronics, witnesses of which we are, causes the progress of the development of the methods of the laser sounding of the atmosphere. In the near future these methods will engage their worthy place in the manifold study program of the atmosphere, realized only by scientific, but also specialists of the wide network of hydrometeorological stations.

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